Chapter 7
Choosing Among Surface Finishing Technologies

This chapter of the Cleaner Technologies Substitutes Assessment (CTSA) organizes data collected or developed throughout the assessment of the baseline non-conveyorized hot air soldering level (HASL) process and alternatives, in a manner that facilitates decision-making. First, risk, competitiveness, and conservation data are summarized in Section 7.1. This information is used in Section 7.2 to assess the private and external benefits and costs (which constitute the societal benefits and costs) of implementing an alternative as compared to the baseline. Section 7.3 provides summary profiles for the baseline and alternatives.

Information is presented for six technologies for performing the surface finishing function. These technologies are HASL, nickel/gold, nickel/palladium/gold, organic solderability preservative (OSP), immersion silver, and immersion tin. All of these technologies are wet chemistry processes, except the HASL technology, which combines a wet chemistry pre-cleaning process with the mechanical process of applying the solder. The wet chemistry processes can be operated using vertical, immersion-type, non-conveyorized equipment or horizontal, conveyorized equipment. The HASL process can be applied in either equipment mode. Table 7-1 presents the processes (alternatives and equipment configurations) evaluated in the CTSA.

Table 7-1. Surface Finishing Processes Evaluated in the CTSA

Surface Finishing Technology	Equipment Configuration	
	Non-Conveyorized	Conveyorized
HASL (Baseline)	X	X
Nickel/Gold	X	
Nickel/Palladium/Gold	X	
OSP	X	X
Immersion Silver		X
Immersion Tin	X	X

The results of the CTSA comparing alternative surface finishes are mixed, with some of the alternatives offering environmental and/or economic benefits, or both, when compared to the baseline non-conveyorized HASL process. The results of the risk screening and comparison of the alternatives were also mixed, while results of the performance demonstration indicate that all of the alternative finishes perform as well as the baseline. In addition, it is important to note that there are additional factors beyond those assessed in this CTSA that individual businesses may consider when choosing among alternatives. None of these sections make value judgements or recommend specific alternatives. The intent of this document is to provide information for decision-makers to consider, although the actual decision of whether or not to implement an alternative is made outside of the CTSA process.

7.1 RISK, COMPETITIVENESS, AND CONSERVATION DATA SUMMARY

Earlier sections of the CTSA evaluated the risk, performance, cost, and resource requirements of the baseline surface finishing technology as well as the alternatives. This section summarizes the findings associated with the analysis of surface finishing technologies. Relevant data include the following:

- Risk information: occupational health risks, public health risks, ecological hazards, and process safety concerns.
- Competitiveness information: technology performance, cost and regulatory status, and international information.
- Conservation information: energy and natural resource use.

Sections 7.1.1 through 7.1.3 present risk, competitiveness, and conservation summaries, respectively.

7.1.1 Risk Summary

The risk screening and comparison uses a health-hazard based framework and a model facility approach to compare the potential health risks of one surface finishing process technology to the potential risks associated with switching to an alternative technology. As much as possible, reasonable and consistent assumptions are used across alternatives. Data to characterize the model facility and exposure patterns for each process alternative were aggregated from a number of sources, including printed wiring board (PWB) shops in the United States, supplier data, and input from PWB manufacturers at project meetings. Thus, the model facility is not entirely representative of any one facility, and actual risk could vary substantially, depending on site-specific operating conditions and other factors.

When using the risk results to compare potential health effects among alternatives, it is important to remember that this is a screening level rather than a comprehensive risk characterization, both because of the predefined scope of the assessment and because of exposure and hazard data limitations. It should also be noted that this approach does not result in any absolute estimates or measurements of risk, and even for comparative purposes, there are several important uncertainties associated with this assessment (see Section 3.4).

The Exposure Assessment, whenever possible, used a combination of central tendency and high-end assumptions, as would be used for an overall high-end exposure estimate. Some values used in the exposure calculations, however, are better characterized as “what-if,” especially pertaining to exposure frequency, bath concentrations, use of gloves, and process area ventilation rates for a model facility. Because some part of the exposure assessment for both inhalation and dermal exposures qualifies as a “what-if” descriptor, the entire assessment should be considered “what-if.”

As with any evaluation of risk, there are a number of uncertainties involved in the measurement and selection of hazard data, and in the data, models, and scenarios used in the exposure assessment. Uncertainties arise both from factors common to all risk characterizations (e.g., extrapolation of hazard data from animals to humans, extrapolation from the high doses used in animal studies to lower doses to which humans may be exposed, and missing toxicity data, including data on the cumulative or synergistic effects of chemical exposure), and other factors that relate to the scope of the risk characterization (e.g., the surface finishing characterization is a screening level characterization rather than a comprehensive risk assessment). Key uncertainties in the risk characterization include the following:

- The risk estimates for occupational dermal exposure are based on limited dermal toxicity data, using oral toxicity data with oral to dermal extrapolation when dermal toxicity data were unavailable. Coupled with the high uncertainty in estimating dermal absorption rates, this could result in either over- or under-estimates of exposure and risk.
- The exposure assessment is based on modeled estimates of average, steady-state chemical concentrations in air, rather than actual monitoring data of average and peak air concentrations.
- The exposure assessment does not account for any side reactions occurring in the baths, which could either underestimate exposures to toxic reaction products or overestimate exposures to toxic chemicals that react in the bath to form more benign chemicals.
- Due to resource constraints, the risk screening and comparison does not address all types of exposures that could occur from surface finishing processes or the PWB industry, including short-term or long-term exposures from sudden releases due to fires, spills, or periodic releases.
- For aquatic risk, surface water concentrations are based on estimated releases to a modeled, representative stream flow for the electronics industrial sector.

The Risk Characterization section of the CTSA (Section 3.4) discusses the uncertainties in this characterization in more detail.

<u>Occupational Health Risks</u>

Health risks to workers are estimated for inhalation exposure to vapors and aerosols from surface finishing baths and for dermal exposure to surface finishing bath chemicals. Inhalation exposure estimates are based on the assumptions that emissions to indoor air from conveyorized lines are negligible, that the air in the process room is completely mixed and chemical concentrations are constant over time, and that no vapor control devices (e.g., bath covers) are used in non-conveyorized lines. Dermal exposure estimates are based on the conservative assumptions that workers do not wear gloves and that all non-conveyorized lines are operated by manual hoist. Dermal exposure to line operators on non-conveyorized lines is estimated for routine line operation and maintenance (e.g., bath replacement, filter replacement), and on conveyorized lines for bath maintenance activities alone.

Based on the number of chemicals with risk results above concern levels, some alternatives to the non-conveyorized HASL process appear to pose lower occupational risks (i.e., immersion silver, conveyorized and non-conveyorized immersion tin, and conveyorized HASL), some may pose similar levels of risk (i.e., conveyorized and non-conveyorized OSP), and some may pose higher risk (i.e., nickel/gold and nickel/palladium/gold). There are occupational inhalation risk concerns for chemicals in the non-conveyorized HASL, nickel/gold, nickel/palladium/gold, and OSP processes. There are also occupational risk concerns for dermal contact with chemicals in the non-conveyorized HASL, nickel/gold, nickel/palladium/gold, OSP, and immersion tin processes, and the conveyorized HASL and OSP processes.

Table 7-2 presents chemicals of concern for potential occupational risk from inhalation. Table 7-3 presents chemicals of concern for potential occupational risk from dermal contact.

Table 7-2. Surface Finishing Chemicals of Concern for Potential Occupational Inhalation Risk

Chemical	Process [a] (Non-Conveyorized, 260,000 ssf)			
	HASL	Nickel/Gold	Nickel/Palladium/Gold	OSP
Alkyldiol		X	X	
Ethylene glycol	X			X
Hydrochloric acid		X	X	
Hydrogen peroxide		X	X	
Nickel sulfate		X	X	
Phosphoric acid		X	X	
Propionic acid			X	

[a] Non-conveyorized immersion silver process not evaluated. Occupational exposure and risk from all conveyorized process configurations are below concern levels.
X Line operator risk results above concern levels (non-cancer health effects).

The non-conveyorized nickel/gold process contains the only chemical for which an occupational cancer risk has been estimated (inorganic metallic salt A). The line operator inhalation exposure estimate for inorganic metallic salt A results in an estimated upper bound excess individual life time cancer risk of 2×10^{-7} (one in five million) based on high end exposure. Cancer risks less than 1×10^{-6} (one in one million) are generally considered to be of low concern. Risks to other types of workers[1] were assumed to be proportional to the average amount of time spent in the process area, which ranged from 12 to 69 percent of the risk for a line operator.

[1] These include laboratory technicians, maintenance workers, and wastewater treatment operators. Other types of workers may be present for shorter or longer times.

Table 7-3. Chemicals of Concern for Potential Dermal Risks

Chemical	Process Configuration [a]						
	HASL (NC)	HASL (C)	Nickel/Gold (NC)	Nickel/ Palladium/Gold (NC)	OSP (NC)	OSP (C)	Immersion Tin (NC)
Ammonia compound A				X			
Ammonium chloride			X				
Ammonium hydroxide			X	X			
Copper ion					XX	XX	
Copper salt C					XX	X	
Copper sulfate pentahydrate	XX	XX	XX	XX	XX	XX	
Ethylene glycol monobutyl ether							X
Hydrogen peroxide			X	X			
Inorganic metallic salt B			XX	XX			
Lead	†	†					
Nickel sulfate			XX	XX			
Urea compound C							X

[a] No risk results were above concern levels for the conveyorized immersion silver or conveyorized immersion tin processes.
X Line operator risk results above concern levels (non-cancer health effects).
XX Line operator and laboratory technician risk results above concern levels (non-cancer health effects).
†: Risk indicators were not calculated for lead as with the other chemicals (see Section 3.4.6). Other information, however, indicates that incidental ingestion of lead from contact with hands could result in lead exposure at levels of concern.
C: Conveyorized (horizontal) process configuration
NC: Non-conveyorized (vertical) process configuration.

Other identified chemicals in the surface finishing processes are suspected or known carcinogens. Lead and thiourea have been determined by IARC to be possible human carcinogens (IARC Group 2B); lead has also been classified by EPA as a probable human carcinogen (EPA Class B2). Lead is used in tin-lead solder in the HASL process. Thiourea is used in the immersion tin process. Urea compound B, a confidential ingredient in the nickel/gold and nickel/palladium/gold processes, is possibly carcinogenic to humans. Exposure for workers from these chemicals has been estimated, but cancer potency and cancer risks are unknown. Additionally, strong inorganic and acid mists of sulfuric acid have been determined by IARC to be a human carcinogen (IARC Group 1). Sulfuric acid is used in diluted form in every surface finishing process in this evaluation. It is not expected, however, to be released to the air as a strong acid mist. There are potential cancer risks to workers from these chemicals, but because there are no slope factors, the risks cannot be quantified.

For non-cancer risk, risk indicators exceeding concern levels – a hazard quotient (HQ) greater than one, a margin of exposure (MOE) based on no-observed adverse effect level (NOAEL) lower than 100, or MOE based on a lowest-observed adverse effect level (LOAEL) lower than 1,000 – were estimated for occupational exposures to chemicals in the non-conveyorized and conveyorized HASL processes, non-conveyorized nickel/gold process, non-conveyorized nickel/palladium/gold process, non-conveyorized and conveyorized OSP processes, and the non-conveyorized immersion tin process.

Based on calculated occupational exposure levels, there may be adverse health effects to workers exposed to chemicals with a HQ exceeding 1.0 or an MOE less than 100 or 1,000. However, it should be emphasized that these conclusions are based on screening level estimates. These numbers are used here for relative risk comparisons between processes, and should not be used as absolute indicators for actual health risks to surface finishing line workers.

Worker blood-lead levels measured at one PWB manufacturing facility were below any federal regulation or guideline for workplace exposure. Modeling data, however, show that it may be possible for blood-lead levels to exceed recommended levels for an adult and fetus, given high incidental ingestion rates of lead from handling solder. These results are highly uncertain; ingestion rates are based on incidental soil ingestion rates for adults in contact with soil. However, this indicates the need for good personal hygiene for HASL line operators, especially wearing gloves and hand washing to prevent accidental hand-to-mouth ingestion of lead.

Public Health Risks

Potential public health risk was estimated for inhalation exposure for the general public living near a PWB facility. Public exposure estimates are based on the assumption that emissions from both conveyorized and non-conveyorized process configurations are vented to the outside. The risk indicators for ambient exposures to humans, although limited to airborne releases, indicate low concern for nearby residents. The upper bound excess individual cancer risk for nearby residents from inorganic metallic salt A in the non-conveyorized nickel/gold process was estimated to be from approaching zero to 2×10^{-11} (one in 50 billion). This chemical has been classified as a human carcinogen.[2] All hazard quotients are less than one for ambient exposure to the general population, and all MOEs for ambient exposure are greater than 1,000 for all processes, indicating low concern from the estimated air concentrations for chronic non-cancer effects.

Estimated ambient air concentrations of lead from a HASL process are well below EPA air regulatory limits for lead, and risks to the nearby population from airborne lead are expected to be below concern levels.

Ecological Risks

We calculated ecological risk indicators (RI_{ECO}) for non-metal surface finishing chemicals that may be released to surface water. Risk indicators for metals are not used for comparing alternatives because it is assumed that on-site treatment is targeted to remove metal so that permitted concentrations are not exceeded. Estimated surface water concentrations for non-metals exceeded the concern concentration (CC) in the following processes: four in the non-

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[2] A cancer classification of known human carcinogen has been assigned by either the EPA, IARC, and/or NTP. Further details about the carcinogen classification are not provided in order to protect the confidential chemical identity.

conveyorized HASL process, three in the conveyorized HASL process, one in the non-conveyorized OSP process, one in the conveyorized OSP process, one in the conveyorized immersion silver process, and one in the non-conveyorized immersion tin process. Table 7-4 presents chemicals of concern based on ecological risk indicator results.

Table 7-4. Aquatic Risk of Non-Metal Chemicals of Concern

Chemical	HASL (NC)	HASL (C)	OSP (NC)	OSP (C)	Immersion Silver (C)	Immersion Tin (NC)
Alkylaryl imidazole			X	X		
Alkylaryl sulfonate	X	X				
1,4-Butenediol	X					
Hydrogen peroxide	X	X			X	
Potassium peroxymonosulfate	X	X				X

Estimated surface water concentration > concern concentration (CC) after POTW treatment.

A CC is the concentration of a chemical in the aquatic environment which, if exceeded, may result in significant risk to aquatic organisms. CCs were determined by dividing acute or chronic toxicity values by an assessment factor (ranging from one to 1,000) that incorporates the uncertainty associated with toxicity data. CCs are discussed in more detail in Section 3.3.3.

Process Safety

Workers can be exposed to two types of hazards affecting occupational safety and health: chemical hazards and process hazards. Workers can be at risk through exposure to chemicals and because of close proximity to automated equipment. In order to evaluate the chemical safety hazards of the various surface finishing technologies, material safety data sheets (MSDSs) for chemical products used with each of the surface finishing technologies were reviewed. Table 7-5 summarizes the hazardous properties of surface finishing chemical products.

Other potential chemical hazards can occur because of hazardous decomposition of chemical products, or chemical product incompatibilities with other chemicals or materials. With few exceptions, most chemical products used in surface finishing technologies can decompose under specific conditions to form potentially hazardous chemicals. In addition, all of the surface finishing processes have chemical products with incompatibilities that can pose a threat to worker safety if the proper care is not taken to prevent such occurrences.

Table 7-5. Chemical Hazards

Process	No. of MSDS [a]	Hazardous Property [b]							
		F	C	E	FH	CO	O	SRP	U
HASL	33	1		1	3	4	1	1	1
Nickel/Gold	19					8	1	1	
Nickel/Palladium/Gold	18					12	1	1	
OSP	9	1			2	4	1	1	
Immersion Silver	4			1	1	2	1		1
Immersion Tin	14			1		7			

[a] For alternative processes with more than one product line, the hazard data reported represent the most hazardous bath of each type for the two product lines (e.g., of the microetch baths from the two product lines, the one with the most hazardous chemicals is reported).
[b] Formulations for HASL process baths were unavailable because cleaner and microetch bath chemistries are not made specifically for the HASL process. Hazards reported for HASL bath types were reported as the worst case of the results of similar baths from other processes.
F = Flammable; C = Combustible; E = Explosive; FH = Fire Hazard; CO = Corrosive; O = Oxidizer; SRP = Sudden Release of Pressure; U = Unstable

Work-related injuries from equipment, improper use of equipment, bypassing equipment safety features, failure to use personal protective equipment, and physical stresses that may appear gradually as a result of repetitive motion are all potential process safety hazards to workers. Regardless of the technology used, of critical importance is an effective and ongoing safety training program. Characteristics of an effective worker health and safety program include:

- an employee training program;
- employee use of personal protective equipment;
- proper chemical storage and handling; and
- safe equipment operating procedures.

Without appropriate training, the number of worker accidents and injuries is likely to increase, regardless of the technology used. A key management responsibility is to ensure that training is not compromised by pressure to meet production demands or by cost-cutting efforts.

7.1.2 Competitiveness Summary

The competitiveness summary provides information on basic issues traditionally important to the competitiveness of a business: the performance characteristics of its products relative to industry standards; the direct and indirect costs of manufacturing its products; and its need or ability to comply with environmental regulations. The final evaluation of a technology involves considering these traditional competitiveness issues along with issues that business leaders now know are equally important issues: the health and environmental impacts of alternative products, processes, and technologies.

Performance

The performance of the surface finishing technologies was tested using production run tests following a strict testing protocol. Functional test boards were fabricated using a complex test board design (a modified version of the IPC-B-24 board) developed by the Circuit Card Assembly and Materials Task Force (CCAMTF). A surface finish was then applied to test boards at each of thirteen volunteer PWB manufacturing facilities. Test boards were then collected together and assembled at an assembly facility, using either a halide-free low-residue flux or a halide-containing water-soluble flux, before being tested under thermal and mechanical stress, and accelerated aging conditions. Additional residue testing was conducted to determine the mechanism of failure. The test methods used to evaluate performance were intended to indicate characteristics of a technology's performance, not to define parameters of performance or to substitute for thorough on-site testing; the study was intended to be a "snapshot" of the technologies. The Performance Demonstration was conducted with extensive input and participation from PWB manufacturers, their suppliers, and PWB testing laboratories. The testing protocol was designed to be consistent with the industry-led CCAMTF testing of surface finishes.

The technologies tested included HASL (baseline), nickel/gold, nickel/palladium/gold, OSP, immersion silver, and immersion tin. The test vehicle measured roughly 6" x 5.8" x 0.062" and was designed to contain at least 80 percent of the circuitry used in military and commercial electronics. The test vehicle was also designed to be representative of a variety of circuits, including high current low voltage (HCLV), high voltage low current (HVLC), high speed digital (HSD), high frequency (HF), stranded wire (SW) and other networks, which were used to measure current leakage. Overall, the vehicle provided 23 separate electrical responses for testing the performance of the surface finish. Types of electrical components in the HCLV, HVLC, HSD, and HF circuits included both plated through hole (PTH) and surface mounted components.

Test sites were submitted by suppliers of the technologies, and included production facilities and supplier testing facilities. Because the test sites were not chosen randomly, the sample may not be representative of all PWB manufacturing facilities (although there is no specific reason to believe that they are not representative). In addition, the number of test sites for each technology ranged from one to four. Due to the smaller number of test sites for some technologies, statistical relevance could not be determined.

The results of the performance testing showed that all of the surface finishes under study were very robust to the environmental exposures, with two exceptions. Failures during the mechanical shock testing, resulting in the separation of the surface mount components, were attributable to the severity of the testing, and spread evenly across all finishing technologies, including the baseline HASL process. Failures in the high frequency, low pass filter circuits, resulting from open PTH, were found to be attributable to a combination of board fabrication materials and board design. From an overall contamination standpoint, the five non-HASL surface finishes performed as well, if not better than the HASL finish. The few solder joint cracking failures were greater with the HASL finish, than with the alternative finishes.

Cost

Comparative costs were estimated using a hybrid cost model that combined traditional costs with simulation modeling and activity-based costs. The cost model was designed to determine the total cost of processing a specific amount of PWB through a fully operational surface finishing line, in this case, 260,000 surface square feet (ssf). Total costs were divided by the throughput to determine a unit cost in $/ssf. Costs not related to the steady-state operation of the surface finishing line, such as start-up costs or the costs of process changes required to other process to implement a change in surface finishing technology, can vary widely by facility and were not estimated by the model.

The cost components considered include capital costs (primary equipment & installation costs, and facility costs), materials costs (limited to chemical costs), utility costs (water, electricity, and natural gas costs), wastewater cost (limited to wastewater discharge cost), production costs (production labor and chemical transport costs), and maintenance costs (tank cleanup, bath setup, sampling and analysis, and filter replacement costs). Other cost components may contribute significantly to overall costs, but were not quantified because they could not be reliably estimated. These include wastewater treatment cost, sludge recycling and disposal cost, other solid waste disposal costs, and quality costs (i.e., costs from decreased production efficiency due to boards that do not meet quality specifications). However, Performance Demonstration results indicate that each surface finishing technology has the capability to achieve comparable levels of performance to HASL. Thus, quality costs are not expected to differ among the alternatives.

Table 7-6 presents results of the cost analysis. The results indicate that all of the surface finishing alternatives were more economical than the baseline non-conveyorized HASL process, with the exception of the two technologies containing gold, an expensive precious metal. Unit costs ranged from $0.10/ssf for the conveyorized OSP process to $1.54/ssf for the non-conveyorized nickel/palladium/gold process. Three processes had a substantial cost savings of at least 50 percent of the cost per ssf over that of the baseline HASL process (conveyorized OSP at 72 percent, non-conveyorized OSP at 69 percent, and non-conveyorized immersion tin at 50 percent). Three other process alternatives realized a somewhat smaller cost savings over the baseline HASL process (conveyorized immersion tin at 31 percent, conveyorized immersion silver at 22 percent, and the conveyorized HASL process at 3 percent).

In general, conveyorized processes cost less than non-conveyorized processes of the same technology due to the cost savings associated with their higher throughput rates. The lone exception, immersion tin, was more costly because the combination of process cycle time and conveyor length resulted in a lower throughput rate than its non-conveyorized version.

Chemical cost was the single largest component cost for all of the nine processes. Labor costs were the second largest cost component, though far less than the cost of process chemicals.

Table 7-6. Cost of Surface Finishing Technologies

Cost Category	Cost Components	HASL (NC)	HASL (C)	Nickel/Gold (NC)
Capital Cost	Primary Equipment & Installation	$9,360	$11,100	$7,260
	Facility	$432	$398	$2,930
Material Cost	Chemicals	$74,800	$75,200	$109,000
Utility Cost	Water	$706	$565	$1,180
	Electricity	$669	$452	$2,360
	Natural Gas	$88	$45	$0
Wastewater Cost	Wastewater Discharge	$1,100	$851	$2,050
Production Cost	Transportation of Material	$167	$130	$668
	Labor for Line Operation	$3,940	$1,790	$19,100
Maintenance Cost	Tank Cleanup	$1,210	$938	$4,820
	Bath Setup	$272	$211	$1,090
	Sampling and Testing	$499	$249	$3,530
	Filter Replacement	$967	$482	$1,580
Total Cost		**$94,200**	**$92,400**	**$156,000**
Unit Cost ($/ssf)		**$0.36**	**$0.35**	**$0.60**

Cost Category	Cost Components	Nickel/Palladium/Gold (NC)	OSP (NC)	OSP (C)
Capital Cost	Primary Equipment & Installation	$15,400	$1,640	$2,880
	Facility	$6,090	$313	$264
Material Cost	Chemicals	$321,000	$18,500	$18,800
Utility Cost	Water	$2,060	$441	$301
	Electricity	$4,050	$313	$208
	Natural Gas	$0	$67	$32
Wastewater Cost	Wastewater Discharge	$3,530	$704	$462
Production Cost	Transportation of Material	$1,030	$158	$121
	Labor for Line Operation	$25,200	$3,170	$1,320
Maintenance Cost	Tank Cleanup	$7,440	$1,140	$871
	Bath Setup	$1,680	$257	$196
	Sampling and Testing	$8,900	$1,610	$738
	Filter Replacement	$2,830	$330	$151
Total Cost		**$399,000**	**$28,700**	**$26,300**
Unit Cost ($/ssf)		**$1.54**	**$0.11**	**$0.10**

Table 7-6. Cost of Surface Finishing Technologies (cont.)

Cost Category	Cost Components	Immersion Silver (C)	Immersion Tin (NC)	Immersion Tin (C)
Capital Cost	Primary Equipment & Installation	$10,500	$2,950	$16,800
	Facility	$937	$892	$2,340
Material Cost	Chemicals	$52,700	$29,000	$28,900
Utility Cost	Water	$301	$1,030	$702
	Electricity	$739	$494	$1,230
	Natural Gas	$140	$162	$240
Wastewater Cost	Wastewater Discharge	$529	$1,620	$1,215
Production Cost	Transportation of Material	$167	$204	$167
	Labor for Line Operation	$5,260	$6,780	$8,770
Maintenance Cost	Tank Cleanup	$1,210	$1,470	$1,210
	Bath Setup	$272	$332	$272
	Sampling and Testing	$937	$1,260	$1,800
	Filter Replacement	$80	$705	$1,000
Total Cost		**$73,800**	**$46,900**	**$64,700**
Unit Cost ($/ssf)		**$0.28**	**$0.18**	**$0.25**

Regulatory Status

Discharges of surface finishing chemicals may be restricted by federal, state, or local air, water, or solid waste regulations, and releases may be reportable under the federal Toxics Release Inventory program. Federal environmental regulations were reviewed to determine the federal regulatory status of surface finishing chemicals.[3] Table 7-7 lists the number of chemicals used in a surface finishing technology with federal environmental regulations restricting or requiring reporting of their discharges. Different chemical suppliers of a technology do not always use the same chemicals in their particular product lines. Thus, all of these chemicals may not be present in any one product line.

[3] In some cases, state or local requirements may be more restrictive than federal requirements. However, due to resource limitations, only federal regulations were reviewed.

Table 7-7. Regulatory Status of Surface Finishing Technologies

Process Chemical	Number of Chemicals Subject to Applicable Regulation														
	CWA				CAA			EPCRA			TSCA			RCRA Waste	
	304b	307a	311	Priority Pollutant	111	112b	112r	313	110	302a	8d HSDR	MTL	8a PAIR	P	U
HASL	1	1	4	1	3	3	1	6	1	3	3	4	3	-	-
Nickel/Gold	6	6	16	6	11	6	1	12	7	3	1	4	3	-	-
Nickel/Palladium/Gold	5	5	12	5	5	5	1	10	6	3	1	4	4	-	-
OSP	2	2	5	2	3	2	1	5	2	2	1	2	1	-	-
Immersion Silver	1	1	5	1	1	1	-	313			-	1	1	-	-
Immersion Tin	1	1	6	1	3	2	1	7	1	2	2	4	3	-	2

Abbreviations and definitions:

CAA - Clean Air Act
CAA 111 - Standards of Performance for New Stationary Sources of Air Pollutants -Equipment Leaks Chemical List
CAA 112b - Hazardous Air Pollutant
CAA 112r - Risk Management Program
CWA - Clean Water Act
CWA 304b - Effluent Limitations Guidelines
CWA 307a - Toxic Pollutants
CWA 311 - Hazardous Substances
CWA - Priority Pollutants
EPCRA - Emergency Planning and Community Right-to-Know Act
EPCRA 302a - Extremely Hazardous Substances
EPCRA 313 - Toxic Chemical Release Inventory

RCRA - Resource Conservation and Recovery Act
RCRA P Waste - Listed acutely hazardous waste
RCRA U Waste - Listed hazardous waste
SARA - Superfund Amendments and Reauthorization Act
SARA 110 - Superfund Site Priority Contaminant
SDWA - Safe Drinking Water Act
SDWA NPDWR - National Primary Drinking Water Rules
SDWA NSDWR - National Secondary Drinking Water Rules
TSCA - Toxic Substances Control Act
TSCA 8d HSDR - Health & Safety Data Reporting Rules
TSCA MTL - Master Testing List
TSCA 8a PAIR - Preliminary Assessment Information Rule

7.1.3 Resource Conservation Summary

Resources typically consumed by the operation of the surface finishing process include water used for rinsing panels, process chemicals used in the process line, energy used to heat process baths and power equipment, and wastewater treatment chemicals. A quantitative analysis of the energy and water consumption rates of the surface finishing process alternatives was performed to determine if implementing an alternative to the baseline process would reduce consumption of these resources during the manufacturing process. A quantitative analysis of both process chemical and treatment chemical consumption could not be performed due to the variability of factors that affect the consumption of these resources. Section 5.1 discusses the role that the surface finishing process has in the consumption of these resources and the factors affecting the consumption rates.

The relative water and energy consumption rates of the surface finishing process alternatives were determined as follows:

- the daily water consumption rate and hourly energy consumption rate of each alternative were determined based on data collected from the PWB Workplace Practices Questionnaire;
- the operating time required to produce 260,000 ssf of PWB was determined using computer simulations models of each of the alternatives; and
- the water and energy consumption rates per ssf of PWB were calculated based on the consumption rates and operating times.

Table 7-8 presents the results of these analyses.

Table 7-8. Energy and Water Consumption Rates of Surface Finishing Alternatives

Process Type	Water Consumption (gal/ssf)	Energy Consumption (Btu/ssf)
HASL, Non-conveyorized (BASELINE)	1.24	218
HASL, Conveyorized	0.99	133
Nickel/Gold, Non-conveyorized	2.06	447
Nickel/Palladium/Gold, Non-conveyorized	3.61	768
OSP, Non-conveyorized	0.77	125
OSP, Conveyorized	0.53	73
Immersion Silver, Conveyorized	0.53	287
Immersion Tin, Non-conveyorized	1.81	289
Immersion Tin, Conveyorized	0.88	522

The water consumption rates for the surface finishing alternatives ranged from a low of 0.53 gal/ssf for the immersion silver and OSP conveyorized processes to a high of 3.6 gal/ssf for the non-conveyorized nickel/palladium/gold process. Several processes were found to consume less water then the HASL baseline, including conveyorized versions of the immersion silver and immersion tin technologies, along with both versions of the OSP process. Conveyorized processes were found to consume less water than non-conveyorized versions of the same process. Primary factors influencing the water consumption rate included the number of rinse tanks and the overall efficiency of the conveyorized processes.

The energy consumption rates for the surface finishing alternatives ranged from 73 Btu/ssf for the conveyorized OSP process to 768 Btu/ssf for the non-conveyorized nickel/palladium/gold process. The results indicate that three surface finishing processes are more energy efficient than the traditional non-conveyorized HASL process (conveyorized HASL, non-conveyorized OSP, and conveyorized OSP), while two others are roughly comparable (conveyorized immersion silver and non-conveyorized immersion tin). It was also found that for alternatives with both types of automation, the conveyorized version of the process is typically the more energy efficient (HASL and OSP), with the notable exception of the immersion tin process.

An analysis of the impacts directly resulting from the consumption of energy by the surface finishing process showed that the generation of the required energy has environmental impacts. Pollutants released to air, water, and soil can result in damage to both human health and the environment. The consumption of natural gas tends to result in releases to the air which contribute to odor, smog, and global warming, while the generation of electricity can result in pollutant releases to all media with a wide range of possible effects. Minimizing the amount of energy usage by the surface finishing process, either by selection of a more energy efficient process or by adopting energy efficient operating practices, will decrease the quantity of pollutants released into the environment resulting from the generation of the energy consumed.

Metals are another natural resource consumed by the surface finishing process. The rate of deposition of metal was calculated for each technology along with the total amount of metal consumed for 260,000 ssf of PWB produced, the average annual PWB production rate reported by facilities using HASL. It was shown that the consumption of close to 300 pounds of lead could be eliminated by replacing the baseline HASL process with an alternative technology (see Section 5.1, Resource Conservation). In cases where waste solder is not routinely recycled or reclaimed, the consumption of as much as 2,500 pounds of lead could be eliminated by replacement of the HASL process. Although several of the alternative technologies rely on the use of small quantities of other metals (especially nickel, palladium, gold, silver, and tin) the OSP technology eliminates metal consumption entirely.

7.2 SOCIAL BENEFITS/COSTS ASSESSMENT

7.2.1 Introduction to Social Benefits/Costs Assessment

Social benefits/costs analysis[4] is a tool used by policy makers to systematically evaluate the impacts to all of society resulting from individual decisions. The decision evaluated in this analysis is the choice of a surface finishing technology. PWB manufacturers have a number of criteria they may use to assess which surface finishing technology they will use. For example, a PWB manufacturer might ask what impact their choice of a surface finishing alternative might have on operating costs, compliance costs, liability costs, and insurance premiums. This business planning process is unlike social benefit/cost analysis, however, because it approaches the comparison from the standpoint of the individual manufacturer and not from the standpoint of society as a whole.

A social benefits/costs analysis seeks to compare the benefits and costs of a given action, while considering both the private and external costs and benefits.[5] Therefore, the analysis will consider both the impact of the alternative surface finishing processes on the manufacturer itself (private costs and benefits) and the impact the choice of an alternative has on external costs and benefits, such as environmental damage and the risk of illness for the general public. External costs are not borne by the manufacturer, but by society. Table 7-9 defines a number of terms used in benefit/cost analysis, including external costs and external benefits.

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[4] The term “analysis” is used here to refer to a more quantitative analysis of social benefits and costs, where a monetary value is placed on the benefits and costs to society of individual decisions. Examples of quantitative benefits/costs analyses are the regulatory impact analyses done by EPA when developing federal environmental regulations. The term “assessment” is used here to refer to a more qualitative examination of social benefits and costs. The evaluation performed in the CTSA process is more correctly termed an assessment because many of the social benefits and costs of the surface finishing technologies are identified, but not monetized.

[5] Private costs typically include any direct costs incurred by the decision-maker and are generally reflected in the manufacturer’s balance sheet. In contrast, external costs are incurred by parties other than the primary participants to the transaction. Economists distinguish between private and external costs because each will affect the decision-maker differently. Although external costs are real costs to some members of society, they are not incurred by the decision-maker and firms do not normally take them into account when making decisions. A common example of these “externalities” is the electric utility whose emissions are reducing crop yields for the farmer operating downwind. The external costs experienced by the farmer in the form of reduced crop yields are not considered by the utility when making decisions regarding electricity production. The farmer’s losses do not appear on the utility’s balance sheet.

Table 7-9. Glossary of Benefits/Costs Analysis Terms

Term	Definition
Exposed Population	The estimated number of people from the general public or a specific population group who are exposed to a chemical through wide dispersion of the chemical in the environment (e.g., DDT). A specific population group could be exposed to a chemical due to its physical proximity to a manufacturing facility (e.g., residents who live near a facility using a chemical), use of the chemical or a product containing a chemical, or through other means.
Exposed Worker Population	The estimated number of employees in an industry exposed to the chemical, process, and/or technology under consideration. This number may be based on market share data as well as estimations of the number of facilities and the number of employees in each facility associated with the chemical, process, and/or technology under consideration.
Externality	A cost or benefit that involves a third party who is not a part of a market transaction; "a direct effect on another's profit or welfare arising as an incidental by-product of some other person's or firm's legitimate activity" (Mishan, 1976). The term "externality" is a general term which can refer to either external benefits or external costs.
External Benefits	A positive effect on a third party who is not a part of a market transaction. For example, if an educational program results in behavioral changes which reduce the exposure of a population group to a disease, then an external benefit is experienced by those members of the group who did not participate in the educational program. For the example of non-smokers exposed to second-hand smoke, an external benefit can be said to result when smokers are removed from situations in which they expose non-smokers to tobacco smoke.
External Costs	A negative effect on a third party who is not part of a market transaction. For example, if a steel mill emits waste into a river which poisons the fish in a nearby fishery, the fishery experiences an external cost as a consequence of the steel production. Another example of an external cost is the effect of second-hand smoke on non-smokers.
Human Health Benefits	Economic benefit from reduced health risks to workers in an industry or business as well as to the general public as a result of switching to less toxic or less hazardous chemicals, processes, and/or technologies. An example would be switching to a less volatile organic compound, lessening worker inhalation exposures as well as decreasing the formation of photochemical smog in the ambient air.
Human Health Costs	The cost of adverse human health effects associated with production, consumption, and disposal of a firm's product. An example is respiratory effects from stack emissions, which can be quantified by analyzing the resulting costs of health care and the reduction in life expectancy, as well as the lost wages as a result of being unable to work.
Illness Costs	A financial term referring to the liability and health care insurance costs a company must pay to protect itself against injury or disability to its workers or other affected individuals. These costs are known as illness benefits to the affected individual.
Indirect Medical Costs	Indirect medical costs associated with a disease or medical condition resulting from exposure to a chemical or product. Examples would be the decreased productivity of patients suffering a disability or death and the value of pain and suffering borne by the afflicted individual and/or family and friends.

Term	Definition
Private (Internalized) Costs	The direct costs incurred by industry or consumers in the marketplace. Examples include a firm's cost of raw materials and labor, a firm's costs of complying with environmental regulations, or the cost to a consumer of purchasing a product.
Social Costs	The total cost of an activity that is imposed on society. Social costs are the sum of the private costs and the external costs. Therefore, in the example of the steel mill, social costs of steel production are the sum of all private costs (e.g., raw material and labor costs) and the sum of all external costs (e.g., the costs associated with the poisoned fish).
Social Benefits	The total benefit of an activity that society receives (i.e., the sum of the private benefits and the external benefits). For example, if a new product yields pollution prevention opportunities (e.g., reduced waste in production or consumption of the product), then the total benefit to society of the new product is the sum of the private benefit (value of the product that is reflected in the marketplace) and the external benefit (benefit society receives from reduced waste).
Willingness-to-Pay	Estimates used in benefits valuation are intended to encompass the full value of avoiding a health or environmental effect. For human health effects, the components of willingness-to-pay include the value of avoiding pain and suffering, impacts on the quality of life, costs of medical treatment, loss of income, and, in the case of mortality, the value of life.

7.2.2 Benefits/Costs Methodology and Data Availability

The methodology for conducting a social benefits/costs assessment can be broken down into four general steps: 1) obtain information on the relative human and environmental risk, performance, cost, process safety hazards, and energy and natural resource requirements of the baseline and the alternatives; 2) construct matrices of the data collected; 3) when possible, monetize the values presented within the matrices; and 4) compare the data generated for the alternative and the baseline in order to produce an estimate of net social benefits. Section 7.1 presented the results of the first task by summarizing risk, competitiveness, and conservation information for the baseline and alternative surface finishing technologies. Section 7.2.3 presents information relevant to private and external benefits and costs, in matrix form and in monetary terms where possible. Section 7.2.4 presents the private and external benefits and costs together to produce an estimate of net social benefits.

Ideally, the analysis would quantify the social benefits and costs of using the alternative and baseline surface finishing technologies, allowing identification of the technology whose use results in the largest net social benefit. However, because of resource and data limitations and because individual users of this CTSA will need to apply results to their own particular situations, the assessment presents a qualitative description of the risks and other external effects associated with each substitute technology compared to the baseline. Benefits derived from a reduction in risk are described and discussed, but not quantified. Nonetheless, the information presented can be very useful in the decision-making process. A few examples are provided to qualitatively illustrate some of the benefit considerations. Personnel in each individual facility will need to examine the information presented, weight each piece according to facility and community characteristics, and develop an independent choice.

7.2.3 Social Benefits/Costs Associated with Choice of Surface Finishing Alternative

The selection of a surface finish results in costs and benefits to society, in the form of both private and external costs and benefits. For example, an alternative that releases less toxic chemicals into the workplace air results in both private and external benefits. The manufacturer pays less for health care costs and worker sick time, while workers benefit from working in a healthier environment. Society as a whole benefits from a more competitive company in the marketplace and from reduced long-term health care costs; in other words, from the cumulative affect of the benefits or costs, both the private and external. This type of example is why particular aspects of the surface finishing process are discussed in terms of both private benefits and costs and external benefits and costs.

Private and/or external costs and benefits may occur in a number of areas, including:
- manufacturing
- occupational health/worker risk;
- public health/population risk;
- wastewater contaminants and ecological risk; and
- energy and natural resource consumption.

Table 7-10 presents an overview of potential private benefits or costs and external benefits or costs associated with the evaluated areas. Each of these is discussed in turn below. While it is difficult to obtain an overall number to express the private benefits and costs of alternative surface finishing processes, some data were quantifiable, such as manufacturing costs. However, in order to determine the overall private benefit/cost comparison, a qualitative discussion of the data is also necessary. Following the discussion of manufacturing costs are discussions of costs associated with occupational and population health risks and other costs or benefits that could not be put in terms of monetary equivalents, but are important to the decision-making process.

Manufacturing

The cost of manufacturing is considered strictly a private cost, with little or no bearing on social costs and benefits. The cost analysis estimated the average manufacturing costs of the surface finishing technologies for several categories of costs. Results of the cost analysis are shown in Table 7-11. Results show that implementation of several of the alternative processes are likely to result in reduced private costs to the manufacturing facility, and that reductions were primarily due to the lower cost of process chemicals between surface finish processes. Other cost components may contribute significantly to overall private costs for a surface finish, but were not quantified because they could not be reliably estimated. These include wastewater treatment cost, sludge recycling and disposal cost, other solid waste disposal costs, and quality costs. Refer to Chapter 4.2, Cost Assessment, for a more detailed discussion of the methodology and results of the cost assessment for surface finish alternatives.

Table 7-10. Potential Private Benefits or Costs Associated with the Selection of a Surface Finish Technology

Evaluation Category	Private Benefit or Cost [a]	External Benefit or Cost [a]
Manufacturing Costs	Capital costs. Materials (chemical) costs. Utility costs. Wastewater discharge costs. Production cost. Maintenance costs.	Not Applicable
Occupational Health/ Worker Risk	Worker sick days. Worker efficiency. Health insurance costs to the PWB manufacturer.	Long-term medical costs to workers. Pain and suffering associated with work-related illness.
Public Health/ Population Risk	Potential liability costs.	Long-term medical costs. Pain and suffering associated with illness.
Wastewater and Ecological Risk	Treatment costs to meet wastewater permit requirements. Possible fines if permits are violated. Increased liability costs.	Loss of ecosystem diversity. Reduction in the recreational value of streams and rivers.
Energy Use	Direct costs from the use of energy in the manufacturing process.	Increased air emissions. Depletion of natural resources.
Water Use	Direct costs from the use of water in the manufacturing process.	Water costs for the surrounding area. Costs paid to treatment facilities to clean the water. Changes to water quality available to society.

[a] A benefit would be a change in a beneficial direction (e.g., ⊂⊃∪⊕⊃↖⊖ capitol costs), while a cost would be a detrimental change (e.g., ∅≪∪⊕⊃↖⊖ worker sick days).

Table 7-11. Overall Manufacturing Cost Comparison

Process	Estimated Cost to Manufacture 260,000 ssf ($/ssf)
HASL, Non-conveyorized	$0.36
HASL, Conveyorized	$0.35
Nickel/Gold, Non-conveyorized	$0.60
Nickel/Palladium/Gold, Non-conveyorized	$1.54
OSP, Non-Conveyorized	$0.11
OSP, Conveyorized	$0.10
Immersion Silver, Conveyorized	$0.28
Immersion Tin, Non-conveyorized	$0.18
Immersion Tin, Conveyorized	$0.25

Private Benefits/Costs. Reductions in the cost of manufacturing are reflected primarily in reduced private costs for the PWB manufacturer. Implementation of an alternative surface finish can potentially result in significant operating cost savings for a manufacturing facility, as shown above. Decreased manufacturing costs allow companies more operating flexibility and are critical to the long-term ability of the manufacturer to remain competitive in the global marketplace.

External Benefits/Costs. There are no significant external benefits derived directly from the cost of manufacturing. However, several aspects that affect the manufacturing cost of the process result in external benefits. For instance, the conservation of water or material results in a more sustainable operating process with reduced environmental burdens that must be borne by society. See the discussion of cost and benefits based on energy and natural resource consumption presented later in this section for a more complete discussion of the external benefits

Costs and Benefits Based on Occupational Health

Operation of the surface finish process requires workers to work in close contact with chemicals, some of which may pose a threat to occupational health. Unacceptably high risks to workers from chemicals in the workplace may hurt company and worker alike. The reduction of risks to workers through the implementation of an alternative surface finish can result in tangible benefits, both private and external.

Health risks to workers were estimated for inhalation exposure to vapors and aerosols from surface finishing baths, and for dermal exposure to surface finishing bath chemicals. Worker risk to chemicals were compared to EPA guidelines for acceptable risk to identify chemicals of concern within the workplace. Occupational cancer risks were estimated for inhalation exposure to inorganic metallic salt A, a suspected or probable human carcinogen in the non-conveyorized nickel/gold process. The cancer risks to worker health from inorganic metallic salt A are below the EPA concern level of one in one million for inhalation exposure. Occupational cancer risks associated with other suspected carcinogens could not be quantified because cancer slope factors have not yet been established for these chemicals.

Table 7-12 summarizes the number of chemicals of concern for the exposure pathways evaluated and lists the number of suspected carcinogens in each technology. Table 7-13 lists potential health effects associated with surface finishing chemicals of concern. Detailed descriptions of the risk assessment methodology and results are presented in Chapter 3, while the risk results are also summarized in Chapter 7.1.

Table 7-12. Summary of Occupational Hazards, Exposures, and Risks of Potential Concern

Surface Finishing Technology	No. of Chemicals of Concern by Pathway [a]		No. of Suspected Carcinogens [d]
	Inhalation [b]	Dermal [c]	
HASL, Non-conveyorized (BASELINE)	1	1	2
HASL, Conveyorized	0	1	2
Nickel/Gold, Non-conveyorized	5	6	3
Nickel/Palladium/Gold, Non-conveyorized	6	6	1
OSP, Non-conveyorized	1	3	1
OSP, Conveyorized	0	3	1
Immersion Silver, Conveyorized	0	0	1
Immersion Tin, Non-conveyorized	0	1	1
Immersion Tin, Conveyorized	0	0	1

[a] Number of chemicals of concern for a surface finishing line operator (the most exposed individual). Occupational health risks could not be quantified for one or more chemicals in each surface finish due to lack of toxicity or chemical property data. See Chapter 3.3 for a more detailed explanation.
[b] See Table 3-30 for further information on inhalation risks.
[c] See Table 3-31 for further information dermal risks.
[d] See Table 3-21 for further information on cancer classifications.

Health endpoints potentially associated with surface finishing chemicals of concern include:

- skin, eye, nose, throat, and respiratory irritation or damage;
- allergic contact dermatitis;
- gastrointestinal/digestive pain or damage;
- kidney damage;
- liver damage; and
- damage to the nervous system and immune system.

Based on the number of chemicals with risk results above concern levels (Table 7-12), some alternatives to the non-conveyorized HASL process may have private and external benefits resulting from reduced occupational risks. These alternatives include the conveyorized HASL, conveyorized immersion silver, and conveyorized and non-conveyorized immersion tin processes. Some alternatives, however, may have increased costs due to higher risks; these include the non-conveyorized nickel/gold and nickel/palladium/gold processes. Potential risks from conveyorized and non-conveyorized OSP are similar to those of non-conveyorized HASL.

It is important to note that surface finishing chemicals are not the only factor contributing toward the illnesses described in Table 7-13; other PWB manufacturing process steps may also contribute toward adverse worker health effects. With the exception of determining the cancer risk from inorganic metallic salt A, the risk characterization did not link exposures of concern with particular adverse health outcomes or with the number of incidences of adverse health outcomes.[6] Thus, the benefits or costs of illnesses avoided by switching to a surface finishing alternative could not be quantified

Private Costs/Benefits. There are potential economic benefits associated with reduced exposure to surface finishing chemicals. Private benefits for PWB manufacturers may include increased worker productivity, increased worker morale, reduced worker absenteeism due to illness, and a reduction in liability and health care insurance costs. While reductions in insurance premiums as a result of pollution prevention are not currently widespread, the opportunity exists for changes in the future.

External Costs/Benefits. External benefits are not as easily quantifiable, but no less important than the private benefits listed above. Many of the health endpoints described in Table 7-13 lead to long-term illnesses in workers that result in hardship for the entire family. Many states are struggling under the economic burden of providing adequate health care to an aging population using an overburdened health care system experiencing rapidly increasing health care costs. External benefits of a switch to an alternative surface finish system may include reductions in illness to workers along with the associated decreases in both short-term and long-term medical costs and insurance premiums. Other benefits include a higher quality of life for workers and their families.

Table 7-13. Potential Health Effects Associated with Surface Finishing Chemicals of Concern

Chemical of Concern	Alternatives with Exposure Levels of Concern	Pathway of Concern [a]	Potential Health Effects
Ammonium chloride	Nickel/Gold	Dermal	Contact with ammonium chloride solution or fumes irritate the eyes. Large doses of ammonium chloride may cause nausea, vomiting, thirst, headache, hyperventilation, drowsiness, and altered blood chemistry. Ammonia fumes are extremely irritating to skin, eyes, and respiratory passages. The severity of effects depends on the amount of dose and duration of exposure.
Ammonia compound A	Nickel/Palladium/Gold	Dermal	
Ammonium hydroxide	Nickel/Gold, Nickel/Palladium/Gold	Dermal	
Alkyldiol	Nickel/Gold, Nickel/Palladium/Gold	Inhalation	Can affect the respiratory system if inhaled, and kidneys if absorbed into the body.

[6] Cancer risk from inorganic metallic salt A exposure was expressed as a probability, but the exposure assessment did not determine the size of the potentially exposed population (e.g., number of surface finishing line operators and others working in the process area). This information would be necessary to estimate the number of illnesses avoided by switching to an alternative from the baseline.

Chemical of Concern	Alternatives with Exposure Levels of Concern	Pathway of Concern [a]	Potential Health Effects
Copper ion and copper salt C	OSP	Dermal	Long-term exposure to high levels of copper may cause liver damage. Copper is not known to cause cancer. The seriousness of the effects of copper can be expected to increase with both level and length of exposure.
Copper sulfate pentahydrate	HASL, Nickel/Gold, Nickel/Palladium/Gold, OSP	Dermal	
Ethylene glycol	HASL, OSP	Inhalation	In humans, low levels of vapors produce throat and upper respiratory irritation. When ethylene glycol breaks down in the body, it forms chemicals that crystallize and can collect in the body, which prevent kidneys from working. The seriousness of the effects can be expected to increase with both level and length of exposure.
Hydrochloric acid	Nickel/Gold, Nickel/Palladium/Gold	Inhalation	Hydrochloric acid in air can be corrosive to the skin, eyes, nose, mucous membranes, respiratory tract, and gastrointestinal tract.
Hydrogen peroxide	Nickel/Gold, Nickel/Palladium/Gold	Inhalation	Hydrogen peroxide in air can irritate the skin, nose, and eyes. Ingestion can damage the liver, kidneys, and gastrointestinal tract.
	Nickel/Gold, Nickel/Palladium/Gold	Dermal	
Inorganic metallic salt B	Nickel/Gold, Nickel/Palladium/Gold	Dermal	Exposure to this material can damage the nervous system, kidneys, and immune system.
Nickel sulfate	Nickel/Gold, Nickel/Palladium/Gold	Inhalation	Skin effects are the most common effects in people who are sensitive to nickel. Workers who breathed very large amounts of nickel compounds have developed lung and nasal sinus cancers.
	Nickel/Gold, Nickel/Palladium/gold	Dermal	
Phosphoric acid	Nickel/Gold, Nickel/Palladium/Gold	Inhalation	Inhaling phosphoric acid can damage the respiratory tract.
Propionic acid	Nickel/Palladium/Gold	Inhalation	No data were located for health effects of propionic acid exposure in humans, although some respiratory effects were seen in laboratory mice.
Urea compound C	Immersion Tin	Dermal	Dermal exposure to urea compound C has resulted in allergic contact dermatitis in workers, and exposure has caused weight loss in mice.

[a] Inhalation concerns only apply to non-conveyorized processes. Dermal concerns may apply to non-conveyorized and/or conveyorized processes (see Table 7-3).

Costs and Benefits Based on Public Health

In addition to worker exposure, members of the general public in close physical proximity to a PWB plant may be exposed to surface finishing chemicals dispersed into the air. Both private and external cost savings could be realized if an alternative surface finish reduced public health risks.

Public health risk was estimated for inhalation exposure for the general populace living near a facility. Risk was characterized for long-term ambient exposures to the population, rather than short-term exposures to high levels of hazardous materials (e.g., fire, spill). The risk indicators for ambient exposures to humans, although limited to airborne releases, indicated low concern from the estimated air concentrations for chronic non-cancer effects. The excess cancer risks were also found to be well below EPA concern levels (one in 50 billion). Refer to Chapter 3 for a description of the risk assessment methodology and results.

These results suggest little change in public health risks would result from a switch to an alternative surface finish technology. While the study found little difference among the alternatives for those public health risks that were assessed, it was not within the scope of this comparison to assess all community health risks. Risk was not characterized for exposure via other pathways (e.g., drinking water, fish ingestion) or short-term or long-term exposures to high levels of hazardous chemicals when there is a spill, fire, or other periodic release.

Private Costs/Benefits. Private benefits could result from reductions in potential liability costs resulting from adverse effects of emissions released from the facility into the environment. Risk results for the nearby public from inhalation of air emissions from a PWB facility indicate that no substantive difference in risk, and thus, liability cost would be realized. However, private cost savings could result from reduced liability for other types of emissions (e.g. releases to surface water) should they pose a threat to human health.

External Costs/Benefits. External benefits could result from reduced medical costs for members of the public who become ill as a result of exposure to emissions from a nearby PWB manufacturing facility. However, because the health risks from air emissions are all of low concern, a change in alternatives would not be expected to result in significant changes to public health. The effects of other emissions on the public, and the resulting differences in external costs/benefits are unknown.

Costs and Benefits Based on Wastewater and Ecological Risks

Surface finishing chemicals in wastewater are potentially damaging to terrestrial and aquatic ecosystems, resulting in private costs borne by manufacturers as well as external costs borne by society. The CTSA evaluated the ecological risks of the baseline and alternatives for aquatic life by calculating ecological risk indicators for non-metal surface finishing chemicals (metals were assumed to be removed by treatment) that may be released to surface water.

Table 7-14 presents the number of chemicals in each technology with an estimated surface water concentration above their CC. CCs are discussed in more detail in Section 3.3.3. These results suggest that all of the alternatives may pose lower private and external costs based on wastewater contaminants and ecological risks than the baseline process.

Table 7-14. Number of Chemicals with Estimated Surface Water Concentration Above Concern Concentration

Surface Finishing Technology	No. of Chemicals
HASL, Non-conveyorized (BASELINE)	4
HASL, Conveyorized	3
Nickel/Gold, Non-conveyorized	0
Nickel/Palladium/Gold, Non-conveyorized	0
OSP, Non-conveyorized	1
OSP, Conveyorized	1
Immersion Silver, Conveyorized	1
Immersion Tin, Non-conveyorized	1
Immersion Tin, Conveyorized	0

Private Costs/Benefits. The primary cost borne by the manufacturer is the cost of pretreating the wastewater to meet wastewater permit requirements. Pretreatment could include both in-line (e.g. electrowinning) or end-of-pipe treatment techniques (see Chapter 6.2). Other potential private costs include possible fines if permits are violated and increased liability costs.

External Costs/Benefits. Pollution of streams and rivers can damage the aquatic ecosystems, endangering species and reducing ecosystem diversity. Wastewater discharged to streams and other surface waters, even if within permit levels, can have effects on the complex ecosystems in ways that are difficult to predict. Reductions in chemicals of concern through the adoption of alternative surface finish technologies preserves ecosystem diversity, while maintaining the recreational value of surface waters for society.

Costs and Benefits Based on Energy and Natural Resources

Conservation of energy and natural resources has become a national priority with effects on both society and the private sector. Energy shortages in western states have caused periodic rolling blackouts responsible for large economic losses to companies, while at the same time driving up energy costs for citizens and companies alike.

The natural resource and energy consumption of the surface finish technologies was assessed in this CTSA. A detailed discussion of the methods used in evaluating individual consumption rates is presented in Chapter 5, Conservation. Table 7-15 summarizes the water and energy consumption rates and percent changes in consumption from the baseline to the surface finishing alternatives. The results suggest that several of the alternatives use less water per ssf, less energy per ssf, or both, than the baseline non-conveyorized HASL process. The consumption rates of other natural resources, such as precious metals, were also evaluated in Chapter 5.

Table 7-15. Energy and Water Consumption of Surface Finishing Technologies

Surface Finishing Technology	Water Consumption		Energy Consumption	
	gal/ssf	% change	Btu/ssf	% change
HASL, Non-conveyorized (BASELINE)	1.24		218	
HASL, Conveyorized	0.99	-20	133	-39
Nickel/Gold, Non-conveyorized	2.06	+66	447	+105
Nickel/Palladium/Gold, Non-conveyorized	3.61	+191	768	+252
OSP, Non-conveyorized	0.77	-38	125	-43
OSP, Conveyorized	0.53	-57	73	-66
Immersion Silver, Non-conveyorized	0.53	-57	287	+32
Immersion Tin, Non-conveyorized	1.81	+46	263	+21
Immersion Tin, Conveyorized	0.88	-29	522	+239

Private Costs/Benefits. Private benefits associated with the conservation of energy and natural resources are reflected in reduced manufacturing costs for the process (see the discussion of costs and benefits associated with manufacturing presented previously in this section).

Indirect private costs may occur in situations of extreme energy or water shortages, affecting the availability and the cost of the resource required. Energy shortages in some western states resulted in energy price increases and rolling blackouts that at times caused the complete shut down of manufacturing facilities, and the loss of income associated with that shut down. Conservation of energy protects the company and society from the affects of an energy crisis, and acts to prevent another crisis from occurring.

External Costs/Benefits. While the private costs of natural resource and energy consumption are reflected directly in the PWB manufacturers bottom line, the external costs and benefits of conservation are no less tangible, becoming a key issue in the national and local debate of public policy. Companies and governments worldwide are moving towards sustainable production goals that will insure the continued availability of our natural resources, while protecting the business and environmental climates.

Energy shortages have placed energy conservation on the front page of public discussion. Reduced energy consumption through conservation results in the preservation of non-renewable supplies of energy-producing raw materials such as coal, natural gas, or oil. Conservation also acts to reduce air emissions resulting from the generation of energy, including compounds such as carbon dioxide, nitrogen dioxide, carbon monoxide, sulfur oxide compounds (SO_x), and particulate matter. Pollution resulting from the generation of energy consumed by surface finish technologies was summarized in Table 5-11 in Section 5.2, Energy Impacts. Environmental and human health concerns associated with these pollutants include global warming, smog, acid rain, and health effects from toxic chemical exposure.

The use of water and consequent generation of wastewater also results in external costs to society. While the private costs of this water usage are included in the cost estimates in Table 7-

15, the external costs are not. Clean water is quickly becoming a scarce resource, and activities that utilize water therefore impose external costs on society. Higher water costs, inadequate water supplies, decreased water supply quality, and higher costs for public treatment facilities due to increased sewage volumes are all potential external costs bourne by society as a result of increased industrial water consumption.

Other Private Benefits and Costs

Table 7-16 gives additional examples of private costs and benefits that could not be quantified in this CTSA. These include wastewater treatment, solid waste disposal, compliance, and improvements in company image that accrue from implementing a substitute. Some of these were mentioned above, but are included in the table due to their importance to overall benefits and costs.

7.2.4 Summary of Benefits and Costs

The objective of a social benefits/costs assessment is to identify those technologies or decisions that maximize net benefits. Ideally, the analysis would quantify the social benefits and costs of using the alternative and baseline surface finishing technologies in terms of a single unit (e.g., dollars) and calculate the net benefits of using an alternative instead of the baseline technology. Due to data limitations, however, this assessment presents a qualitative description of the benefits and costs associated with each technology compared to the baseline.

Each alternative presents a mixture of private and external benefits and costs. In terms of worker health risks, conveyorized processes have the greatest benefits for reduced worker inhalation exposure to bath chemicals; they are enclosed and vented to the atmosphere. However, dermal contact from bath maintenance activities can be of concern regardless of the equipment configuration for HASL and OSP processes, as well as non-conveyorized nickel/gold, nickel/palladium/gold, and immersion tin processes. Little or no improvement is seen in public health risks because concern levels were very low for all technologies. Differences in estimated wastewater contaminant levels and aquatic risk concerns suggest that alternatives to non-conveyorized HASL post lower potential private and external costs (or higher benefits). Conveyorized processes consumed less water than that consumed by non-conveyorized processes, resulting in net private and external benefits. Only the OSP technology, along with the conveyorized HASL technology, are expected to reduce potential private and external costs of energy consumption, resulting in increased social benefits.

Other benefits and costs discussed qualitatively include wastewater treatment, solid waste disposal, compliance costs, and effects on the company image. The effects on jobs of wide-scale adoption of an alternative was not evaluated in the CTSA.

Table 7-16. Examples of Private Costs and Benefits Not Quantified

Category	Description of Potential Costs or Benefits
Wastewater Treatment	Alternatives to the baseline HASL technology may provide cost savings by reducing the quantity and improving the treatability of process wastewaters. In turn, these cost savings can enable the implementation of other pollution prevention measures. Several alternatives to the baseline process use less rinse water and, consequently, produce less wastewater. However, some alternatives may also introduce additional metals, such as silver or nickel, whicht are toxic to aquatic organisms. These metals, which might not otherwise be present in the plant wastewater, may require additional treatment steps. All of these factors contribute to both the private benefits and costs of implementing a surface finishing alternative.
Solid Waste Disposal	All of the alternatives result in the generation of sludge, off-specification PWBs, and other solid wastes, such as spent bath filters or solder dross. These waste streams must be recycled or disposed of, some of them as hazardous waste. For example, many PWB manufacturers send the contaminated copper waste generated by the HASL process to a recycler to reclaim the metal content. Solder wastes that cannot be effectively reclaimed will likely be landfilled. It is likely that the manufacturer will incur costs in order to recycle or landfill these solid wastes; however, these costs were not quantified (reducing the volume and toxicity of solid waste also provides social benefits to the community).
Compliance Costs	The cost of complying with all environmental and safety regulations affecting the surface finish process line was not quantified. However, chemicals and wastes from several of the surface finish alternatives posed similar environmental compliance problems as the HASL baseline. Two alternatives were subject to greater overall federal environmental regulations than the baseline, suggesting that implementing those alternatives could potentially increase compliance costs. It is easier to assess the relative cost of complying with OSHA requirements, because several of the alternatives pose reduced occupational safety hazards (non-automated, non-conveyorized equipment may also pose less overall process hazards than working with mechanized equipment).
Company Image	Many businesses are finding that using cleaner technologies results in less tangible benefits, such as an improved company image and improved community relations. The elimination of lead from consumer products has been a key feature in many company marketing plans. While it is difficult to put a monetary value on these benefits, they should be considered in the decision-making process.

7.3 TECHNOLOGY SUMMARY PROFILES

This section of the CTSA presents summary profiles of each of the surface finishing technologies. The profiles summarize key information from various sections of the CTSA, including the following:

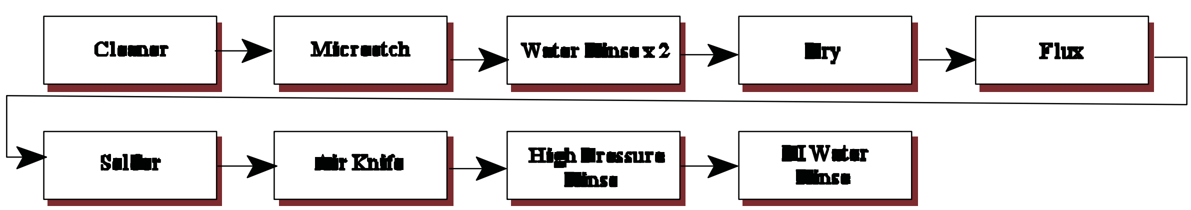
- generic process steps, typical bath sequences, and equipment configurations evaluated in the CTSA;
- human health and environmental hazards data and risk concerns for non-proprietary chemicals;
- production costs and resource (water and energy) consumption data;
- Federal environmental regulations affecting chemicals in each of the technologies; and
- conclusions of the social benefits/costs assessment.

The summary profiles in this section present data for the HASL, nickel/gold, nickel/palladium/gold, OSP, immersion silver, and the immersion tin technologies, respectively. Data are presented for both the non-conveyorized and the conveyorized equipment configurations, when applicable.

As discussed in Section 7.2, each of the alternatives appear to provide benefits in at least one or more areas over the non-conveyorized HASL (the baseline process). However, the overall benefits or costs associated with the alternatives could not be quantified without a more thorough assessment of the factors involved. The actual decision of whether or not to implement an alternative occurs outside of the CTSA process. Individual decision-makers may consider a number of additional factors, such as their individual business circumstances and community characteristics, together with the information presented in this CTSA.

7.3.1 HASL Technology

__Generic Process Steps and Typical Bath Sequence__



__Equipment Configurations Evaluated__: Non-conveyorized (the baseline process) and conveyorized.

Risk Screening and Comparison

Table 7-17 summarizes human and environmental hazards and risk concerns for chemicals in the HASL technology. The risk characterization identified occupational inhalation risk concerns for one chemical in the non-conveyorized HASL process and dermal risk concerns for two chemicals for either equipment configuration. No public health risk concerns were identified for the pathways evaluated.

Table 7-17. Summary of Human Health and Environmental Risk Concerns for the HASL Technology

Chemical	Human Health Hazard and Occupational Risk [a]			Carcinogenicity Weight-of-Evidence Classification	Aquatic Risk Concerns
	Inhalation Risk Concerns [b]	Dermal Risk Concerns [c]	SAT Rank [d]		
1,4-Butenediol	NE	NE	LM	None	NC: Yes C: No
Alkylalkyne diol	NA	No [e]	L	None	No
Alkylaryl sulfonate	NE	No [e]	L	None	Yes
Alkylphenol ethoxylate	NA	No [e]	LM	None	No
Alkylphenol polyethoxyethanol	NA	No [e]	LM	None	No
Arylphenol	NE	No	M	None	No
Citric acid	NA	No [e]	L	None	No
Copper sulfate pentahydrate	NA	Yes		Not classifiable (EPA Class D)	Not considered
Ethoxylated alkylphenol	NA	No [e]	LM	None	No
Ethylene glycol	Yes	No		None	No
Ethyleneglycol monobutyl ether	No	No		None	No
Fluoboric acid	NA	NE		None	No
Gum	NA	No [e]		None	No
Hydrochloric acid	No	NE		Not classifiable (IARC Group 3)	No
Hydrogen peroxide	No	No		Not classifiable (IARC Group 3)	Yes
Hydroxyaryl acid	NA	No [e]	M	None	No
Hydroxyaryl sulfonate	NA	No [e]	LM	None	No
Lead	No	Yes [f]		Probable or possible human carcinogen (EPA Class B2; IARC Group 2 B)	No water releases expected
Phosphoric acid	No	No		None	No

Chemical	Human Health Hazard and Occupational Risk [a]			Carcinogenicity Weight-of-Evidence Classification	Aquatic Risk Concerns
	Inhalation Risk Concerns [b]	Dermal Risk Concerns [c]	SAT Rank [d]		
Potassium peroxymonosulfate	NA	No [e]	M	None	Yes
Sodium benzene sulfonate	NA	No [e]	M	None	No
Sodium hydroxide	NA	NE		None	No
Sulfuric acid	NA	NE [g]		Human carcinogen (IARC Group 1)	No
Tin	NA	NE		None	No water releases expected
Summary	No or NA: 20 NE: 3 Yes: 1	No: 16 NE: 6 YES: 2		2 suspected or known	No: 19 Yes: 4 Not considered: 1

[a] Risk concerns are for surface finishing line operators (the most exposed individual).
[b] Inhalation risk concerns for non-conveyorized process only. Inhalation risk from fully enclosed, conveyorized process is assumed to be negligible.
[c] Dermal risk concerns apply to both conveyorized and non-conveyorized equipment.
[d] Structure-Activity Team rank for human health concerns:
L: Low concern; LM: Low-Moderate concern; M: Moderate concern.
[e] Chemical has very low skin absorption (based on EPA's Structure-Activity Team evaluation); risk from dermal exposure not expected to be of concern.
[f] Lead evaluated by modeling potential blood-lead levels from incidental ingestion.
[g] Although chronic toxicity values have not been established, repeated skin contact with low concentrations of sulfuric acid causes skin desiccation, ulceration of the hands, and chronic inflammation around the nails.
NE: Not Evaluated; due to lack of toxicity measure.
NA: Not Applicable. Inhalation exposure was not calculated because the chemical is not volatile (vapor pressure below 1×10^{-3} torr) and is not used in any air-sparged bath.

Performance

The performance of the HASL technology was demonstrated at four test facilities, one of which operated conveyorized HASL equipment. Performance test results were not differentiated by the type of equipment configuration used. The Performance Demonstration determined that each of the alternative technologies has the capability of achieving comparable levels of performance to the HASL finish.

Production Costs and Resource Consumption

Computer simulation was used to model key operating parameters, including the time required to process a job consisting of 260,000 ssf and the amount of resources (water and energy) consumed. This information was analyzed with a hybrid cost model of traditional cost (i.e., capital costs, etc.) and activity-based costs to determine average manufacturing costs per ssf and water and energy consumption per ssf.

Average manufacturing costs for the baseline process (the non-conveyorized HASL process) were $0.36/ssf, while water and energy consumption were 1.24 gal/ssf and 218 Btu/ssf, respectively. However, the conveyorized HASL process consumed less water and energy and was more cost-effective than the baseline process (non-conveyorized HASL). Figure 7-1 lists the results of the production cost and resource consumption analyses for the conveyorized HASL process and illustrates the percent changes in costs and resource consumption from the baseline. Manufacturing costs, water consumption, and energy consumption are less than the baseline by three percent, 20 percent, and 39 percent, respectively.

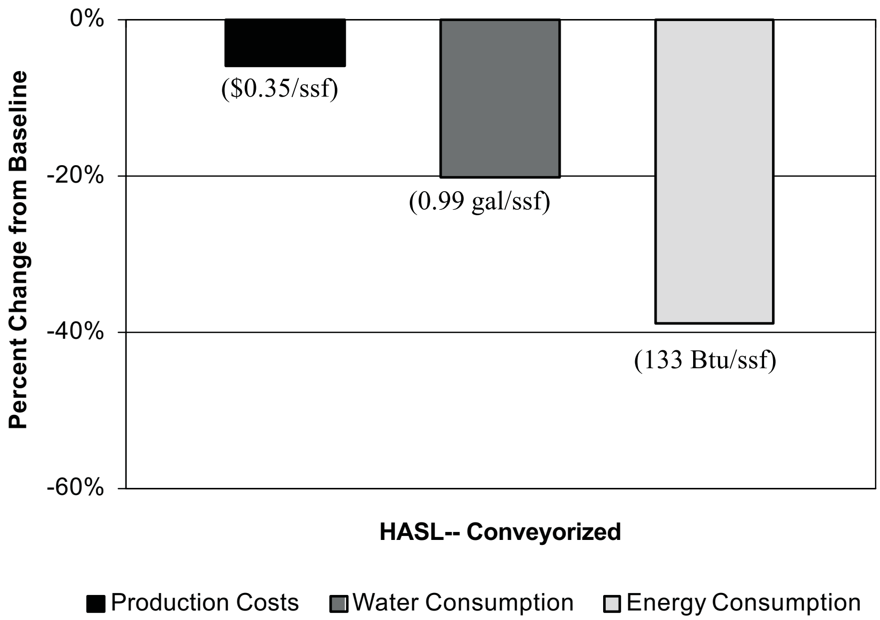


Figure 7-1. Production Costs and Resource Consumption of Conveyorized HASL Technology
(Percent Change from Baseline with Actual Values in Parentheses)

Regulatory Concerns

Chemicals contained in the HASL technology are regulated by the Clean Water Act (CWA), the Clean Air Act (CAA), the Emergency Planning and Community Right-to-Know Act (EPCRA), the Superfund Amendments and Reauthorization Act (SARA), and the Toxic Substances Control Act (TSCA). A summary of the number of HASL chemicals subject to applicable federal regulations is presented in Table 7-18.

Table 7-18. Number of HASL Chemicals Subject to Applicable Federal Regulations

Regulation		No. of Chemicals	Regulation		No. of Chemicals
CWA	304b	1	EPCRA	313	6
	307a	1		302a	3
	311	4	SARA	110	1
	Priority Pollutant	1	TSCA	8d HSDR	3
CAA	111	3		MTL	4
	112b	3		8a PAIR	3
	112r	1	RCRA	U	--

Abbreviations and Definitions:
CWA 304b - Effluent Limitations Guidelines
CWA 307a - Toxic Pollutants
CWA 311 - Hazardous Substances
CAA 111 - Standards of Performance for New Stationary Sources of Air Pollutants-Equipment Leaks Chemical List
CAA 112b - Hazardous Air Pollutant
CAA 112r - Risk Management Program
EPCRA 313 - Toxic Chemical Release Inventory
EPCRA 302a - Extremely Hazardous Substances
SARA 110 - Superfund Site Priority Contaminant
TSCA 8d HSDR - Health & Safety Data Reporting Rules
TSCA MTL - Master Testing List
TSCA 8a PAIR - Preliminary Assessment Information Rule
RCRA U Waste - Characteristic hazardous waste

Social Benefits and Costs

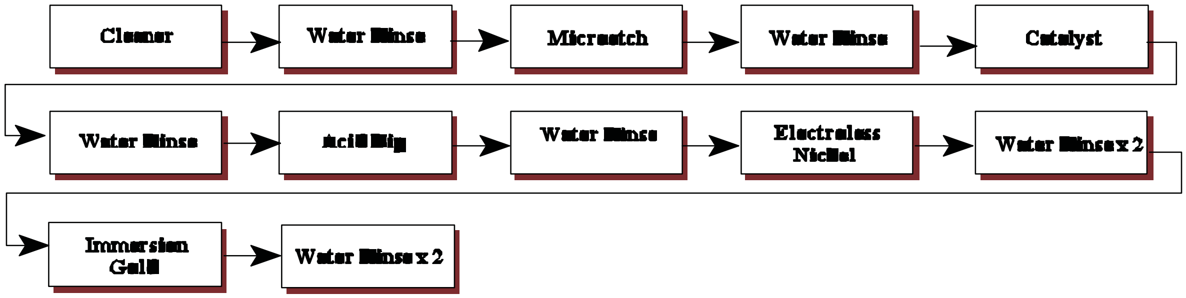
Social cost is the total cost that an activity imposes on society (i.e., the sum of private and external costs) while social benefit is the total benefit of an activity that society receives (i.e., the sum of the private benefits and the external benefits). A qualitative assessment of the social benefits and costs of the baseline and alternative technologies was performed to determine if there would be net benefits or costs to society if PWB manufacturers switched to alternative technologies from the baseline. (Net cost or benefit could not be completely assessed without a more thorough assessment of effects on jobs and wages.)

In comparing the baseline (non-conveyorized HASL) to conveyorized HASL, there appears to be a net benefit for switching to conveyorized HASL because — for the aspects included in the evaluation — results are similar to or better than the baseline. Specifically, changing from baseline to conveyorized HASL may result in:

- benefits from decreased worker and ecological risk (based on fewer chemicals of concern), decreased water use, and decreased energy use; and
- no discernible cost or benefit for manufacturing cost and risk to the public.

7.3.2 Nickel/Gold Technology

Generic Process Steps and Typical Bath Sequence



Equipment Configurations Evaluated: Conveyorized.

Risk Screening and Comparison

Table 7-19 summarizes human and environmental hazards and risk concerns for chemicals in the nickel/gold technology. The risk characterization identified occupational inhalation risk concerns for five chemicals and dermal risk concerns for six chemicals in the non-conveyorized nickel/gold process. No public health risk concerns were identified for the pathways evaluated, although cancer risks as high as one in 50 billion were estimated for the non-conveyorized nickel/gold process.

Table 7-19. Summary of Human Health and Environmental Risk Concerns for the Nickel/Gold Technology

Chemical	Human Health Hazard and Occupational Risks [a]			Carcinogenicity Weight-of-Evidence Classification	Aquatic Risk Concerns
	Inhalation Risk Concerns [b]	Dermal Risk Concerns [c]	SAT Rank [d]		
Aliphatic acid A	NE	No		None	No
Aliphatic acid B	NE	No [e]	M	None	No
Aliphatic acid E	NE	NE		None	No
Aliphatic dicarboxylic acid A	NE	No [e]	LM	None	No
Aliphatic dicarboxylic acid C	NE	No		None	No
Alkylamino acid B	NA	NE		None	No
Alkyldiol	Yes	No		None	No
Alkylphenol polyethoxyethanol	NA	No [e]	LM	None	No
Ammonia compound B	NE	No [e]	MH	None	No
Ammonium chloride	NA	Yes		None	No

Chemical	Human Health Hazard and Occupational Risks [a]			Carcinogenicity Weight-of-Evidence Classification	Aquatic Risk Concerns
	Inhalation Risk Concerns [b]	Dermal Risk Concerns [c]	SAT Rank [d]		
Ammonium hydroxide	No	Yes		None	No
Citric acid	NA	No [e]	L	None	No
Copper sulfate pentahydrate	NA	Yes		Not classifiable (EPA Class D)	Not considered
Ethoxylated alkylphenol	NA	No [e]	LM	None	No
Hydrochloric acid	Yes	NE		Not classifiable (IARC Group 3)	No
Hydrogen peroxide	Yes	Yes		Not classifiable (IARC Group 3)	No
Hydroxyaryl acid	NA	No [e]	M	None	No
Inorganic metallic salt A	No	No		Human carcinogen or probable human carcinogen [f]	Not considered
Inorganic metallic salt B	No	Yes		Probable or possible human carcinogen [f]	Not considered
Inorganic metallic salt C	No	No		Probable or possible human carcinogen [f]	Not considered
Malic acid	NE	No [e]	M	None	No
Nickel sulfate	Yes	Yes		None	Not considered
Palladium chloride	NA	NE		None	Not considered
Phosphoric acid	Yes	No		None	No
Potassium compound	NE	NE	L	None	No
Potassium gold cyanide	NA	No		None	Not considered
Potassium peroxymonosulfate	NA	No [e]	M	None	No
Sodium hydroxide	NA	NE		None	No
Sodium hypophosphite	NE	No [e]	LM	None	No
Sodium salt	NA	No		None	No
Substituted amine hydrochloride	NA	No [e]	M	None	No
Sulfuric acid	NA	NE [g]		Human carcinogen (IARC Group 1)	No
Transition metal salt	NA	No [e]	M	None	Not considered
Urea compound B	NE	NE		Possible human carcinogen [f]	No

Chemical	Human Health Hazard and Occupational Risks [a]			Carcinogenicity Weight-of-Evidence Classification	Aquatic Risk Concerns
	Inhalation Risk Concerns [b]	Dermal Risk Concerns [c]	SAT Rank [d]		
Summary	No or NA: 19 NE: 10 Yes: 5	No: 20 NE: 8 Yes: 6		5 suspected or known	No: 26 Yes: 0 Not considered: 8

[a] Risk concerns are for surface finishing line operators (the most exposed individual).
[b] Inhalation risk concerns for non-conveyorized process only. Inhalation risk from fully enclosed, conveyorized process is assumed to be negligible.
[c] Dermal risk concerns apply to both conveyorized and non-conveyorized equipment.
[d] Structure-Activity Team rank for human health concerns:
L: Low concern; LM: Low-Moderate concern; M: Moderate concern; MH: Moderate-High concern.
[e] Chemical has very low skin absorption (based on EPA's Structure-Activity Team evaluation); risk from dermal exposure is not expected to be of concern.
[f] Specific EPA and/or IARC groups not reported in order to protect proprietary chemical identities.
[g] Although chronic toxicity values have not been established, repeated skin contact with low concentrations of sulfuric acid causes skin desiccation, ulceration of the hands, and chronic inflammation around the nails.
NE: Not Evaluated; due to lack of toxicity measure.

Performance

The performance of the nickel/gold technology was demonstrated at three test facilities. The Performance Demonstration determined that this technology has the capability of achieving comparable levels of performance to the HASL finish. In addition, the nickel/gold process is both gold and aluminum wire-bondable, though testing of wire-bondability was not included in the performance testing protocol.

Production Costs and Resource Consumption

Computer simulation was used to model key operating parameters, including the time required to process a job consisting of 260,000 ssf and the amount of resources (water and energy) consumed. This information was analyzed with a hybrid cost model of traditional cost (i.e., capital costs, etc.) and activity-based costs to determine average manufacturing costs per ssf and water and energy consumption per ssf.

Analyses results determined that the non-conveyorized nickel/gold technology consumed more water and energy and was less cost-effective than the baseline non-conveyorized HASL. Average production costs for nickel/gold were $0.60/ssf, while water and energy consumption rates were determined to be 2.06 gal/ssf and 447 Btu/ssf, respectively. Figure 7-2 lists the results of these analyses and illustrates the percent changes in costs and resources consumption from the baseline. Manufacturing costs, water consumption, and energy consumption are more than the baseline by 67 percent, 66 percent, and 105 percent, respectively.

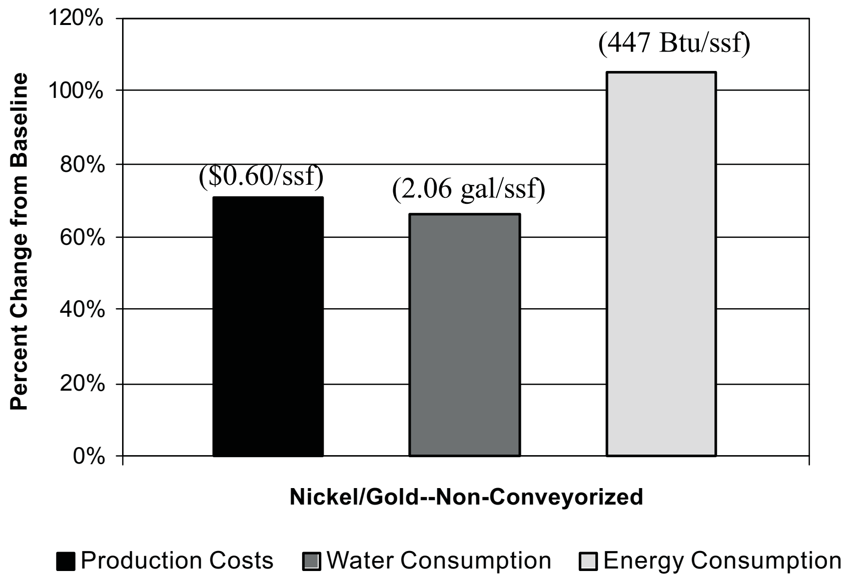


Figure 7-2. Production Costs and Resource Consumption of the Nickel/Gold Technology (Percent Change from Baseline with Actual Values in Parentheses)

Regulatory Concerns

Chemicals contained in the nickel/gold technology are regulated by the CWA, CAA, EPCRA, SARA, and TSCA. None of the nickel/gold process chemicals were regulated under RCRA. A summary of the number of nickel/gold chemicals subject to applicable federal regulations is presented in Table 7-20.

Social Benefits and Costs

A qualitative assessment of the private and external benefits and costs of the this technology suggests a mixture of benefits and costs to society if PWB manufacturers switched to the nickel/gold technology from the baseline. (Net social cost or benefit could not be determined.) For the aspects included in the evaluation, changing from baseline to nickel/gold may result in:

- costs from increased manufacturing cost, increased worker risk (based on fewer chemicals of concern), increased water and energy use;
- benefits from decreased ecological risk (based on fewer chemicals of concern); and
- no discernible cost or benefit for risk to the public.

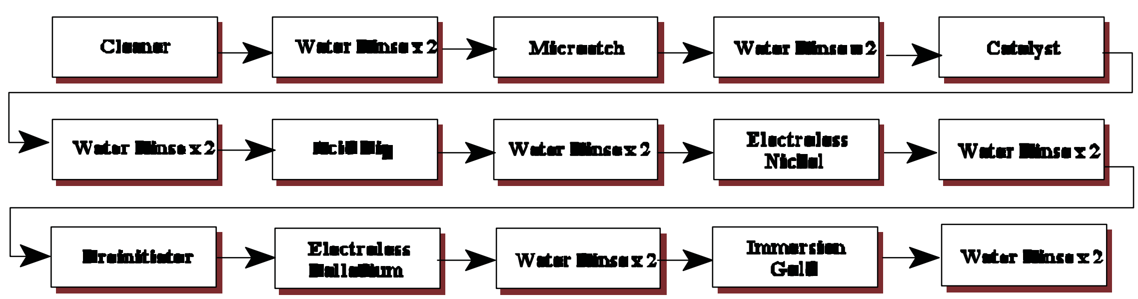
Table 7-20. Number of Nickel/Gold Chemicals Subject to Applicable Federal Regulations

Regulation		No. of Chemicals	Regulation		No. of Chemicals
CWA	304b	6	EPCRA	313	12
	307a	6		302a	3
	311	16	SARA	110	7
	Priority Pollutant	6	TSCA	8d HSDR	1
CAA	111	11		MTL	4
	112b	6		8a PAIR	3
	112r	1	RCRA	U	--

Abbreviations and Definitions:
CWA 304b - Effluent Limitations Guidelines
CWA 307a - Toxic Pollutants
CWA 311 - Hazardous Substances
CAA 111 - Standards of Performance for New Stationary Sources of Air Pollutants-Equipment Leaks Chemical List
CAA 112b - Hazardous Air Pollutant
CAA 112r - Risk Management Program
EPCRA 313 - Toxic Chemical Release Inventory
EPCRA 302a - Extremely Hazardous Substances
SARA 110 - Superfund Site Priority Contaminant
TSCA 8d HSDR - Health & Safety Data Reporting Rules
TSCA MTL - Master Testing List
TSCA 8a PAIR - Preliminary Assessment Information Rule
RCRA U Waste - Characteristic hazardous waste

7.3.3 Nickel/Palladium/Gold Technology

<u>**Generic Process Steps and Typical Bath Sequence**</u>



Equipment Configurations Evaluated: Non-conveyorized.

Risk Screening and Comparison

Table 7-21 summarizes human and environmental hazards and risk concerns for chemicals in the nickel/palladium/gold technology. The risk characterization identified occupational inhalation risk concerns for six chemicals and dermal risk concerns for six chemicals in the non-conveyorized nickel/palladium/gold process. No public health risk concerns were identified for the pathways evaluated.

Table 7-21. Summary of Human Health and Environmental Risk Concerns for the Nickel/Palladium/Gold Technology

Chemical	Human Health Hazard and Occupational Risks [a]			Carcinogenicity Weight-of-Evidence Classification	Aquatic Risk Concerns
	Inhalation Risk Concerns [b]	Dermal Risk Concerns [c]	SAT Rank [d]		
Aliphatic acid B	NE	NE	M	None	No
Aliphatic acid E	NE	No		None	No
Aliphatic dicarboxylic acid A	NE	NE	LM	None	No
Aliphatic dicarboxylic acid C	NE	No		None	No
Alkylamino acid B	NA	No		None	No
Alkyldiol	Yes	No		None	No
Alkyl polyol	NA	No		None	No
Amino acid salt	NA	NE	LM	None	No
Amino carboxylic acid	NA	No		None	No
Ammonia compound A	NA	Yes		None	No
Ammonia compound B	NE	NE	MH	None	No
Ammonium hydroxide	No	Yes		None	No
Citric acid	NA	No [e]	L	None	No
Copper sulfate pentahydrate	NA	Yes		Not classifiable (EPA Class D)	Not considered
Ethoxylated alkylphenol	NA	No [e]	LM	None	No
Ethylenediamine	No	No		None	No
Hydrochloric acid	Yes	NE		Not classifiable (IARC Group 3)	No
Hydrogen peroxide	Yes	Yes		Not classifiable (IARC Group 3)	No
Hydroxyaryl acid	NA	No [e]	M	None	No
Inorganic metallic salt B	No	Yes		Probable or possible human carcinogen [f]	Not considered
Maleic acid	NA	No [e]	M	None	No
Malic acid	NE	No [e]	LM	None	No
Nickel sulfate	Yes	Yes		None	Not considered

Chemical	Human Health Hazard and Occupational Risks [a]			Carcinogenicity Weight-of-Evidence Classification	Aquatic Risk Concerns
	Inhalation Risk Concerns [b]	Dermal Risk Concerns [c]	SAT Rank [d]		
Palladium salt	NA	NE		None	Not considered
Phosphoric acid	Yes	No		None	No
Potassium compound	NE	NE	L	None	No
Potassium gold cyanide	NA	No		None	Not considered
Propionic acid	Yes	No		None	No
Sodium hydroxide	NA	NE		None	No
Sodium hypophosphite monohydrate	NE	No [e]	LM	None	No
Sodium salt	NA	No		None	No
Substituted amine hydrochloride	NA	No [e]	M	None	No
Sulfuric acid	NA	NE [g]		Human carcinogen (IARC Group 1)	No
Surfactant	NA	NE		None	NE
Transition metal salt	NA	No [e]	M	None	Not considered
Urea compound B	NE	NE		Possible human carcinogen [f]	No
Summary	No or NA: 21 NE: 9 Yes: 6	No: 19 NE: 11 Yes: 6		2 suspected or known	No: 29 Yes: 0 Not considered: 6

[a] Risk concerns are for surface finishing line operators (the most exposed individual).
[b] Inhalation risk concerns for non-conveyorized process only. Inhalation risk from fully enclosed, conveyorized process is assumed to be negligible.
[c] Dermal risk concerns apply to both conveyorized and non-conveyorized equipment.
[d] Structure-Activity Team rank for human health concerns:
L: Low concern; LM: Low-Moderate concern; M: Moderate concern; MH: Moderate-High concern.
[e] Chemical has very low skin absorption (based on EPA's Structure-Activity Team evaluation); risk from dermal exposure not expected to be of concern.
[f] Specific EPA and/or IARC groups not reported in order to protect proprietary chemical identities.
[g] Although chronic toxicity values have not been established, repeated skin contact with low concentrations of sulfuric acid causes skin desiccation, ulceration of the hands, and chronic inflammation around the nails.
NE: Not Evaluated; due to lack of toxicity measure.
NA: Not Applicable. Inhalation exposure level was not calculated because the chemical is not volatile (vapor pressure below 1 x 10^{-3} torr) and is not used in any air-sparged bath.

Performance

The performance of the nickel/palladium/gold technology was demonstrated at one test facility. The Performance Demonstration determined that this technology has the capability of achieving comparable levels of performance to the HASL finish. In addition, the nickel/palladium/gold process is both gold and aluminum wire-bondable, though testing of wire-bondability was not included in the performance testing protocol.

Production Costs and Resource Consumption

Computer simulation was used to model key operating parameters, including the time required to process a job consisting of 260,000 ssf and the amount of resources (water and energy) consumed. This information was analyzed with a hybrid cost model of traditional cost (i.e., capital costs, etc.) and activity-based costs to determine average manufacturing costs per ssf and water and energy consumption per ssf.

The non-conveyorized nickel/palladium/gold technology consumed more water and energy than the baseline process (non-conveyorized HASL). Average production costs for nickel/palladium/gold were $1.54/ssf, while water and energy consumption rates were 3.61 gal/ssf and 768 Btu/ssf, respectively. Figure 7-3 lists the results of these analyses and illustrates the percent changes in resources consumption from the baseline. Manufacturing costs, water consumption, and energy consumption are greater than the baseline by 327 percent, 191 percent, and 252 percent, respectively.

Regulatory Concerns

Chemicals contained in the nickel/palladium/gold technology are regulated by the CWA, CAA, EPCRA, SARA, and TSCA. None of the nickel/palladium/gold process chemicals were regulated under RCRA. A summary of the number of nickel/palladium/gold chemicals subject to applicable federal regulations is presented in Table 7-22.

Social Benefits and Costs

A qualitative assessment of the private and external benefits and costs of the this technology suggests a mixture of benefits and costs to society if PWB manufacturers switched to the nickel/palladium/gold technology from the baseline. (Net social cost or benefit could not be determined.) For the aspects included in the evaluation, changing from baseline to nickel/palladium/gold may result in:

- costs from increased manufacturing cost, increased worker risk (based on fewer chemicals of concern), increased water and energy use;
- benefits from decreased ecological risk (based on fewer chemicals of concern); and
- no discernible cost or benefit for risk to the public.

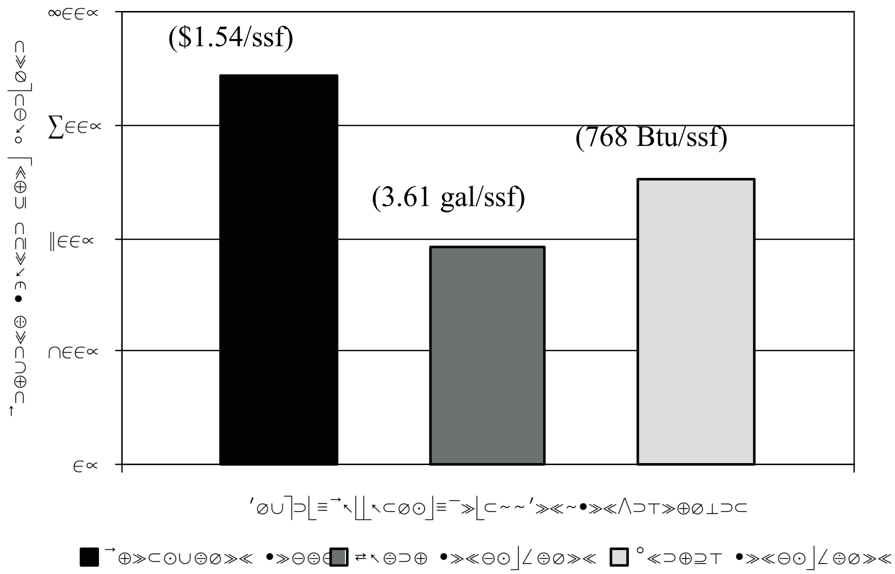


Figure 7-3. Production Costs and Resource Consumption of Nickel/Palladium/Gold Technology
(Percent Change from Baseline with Actual Values in Parentheses)

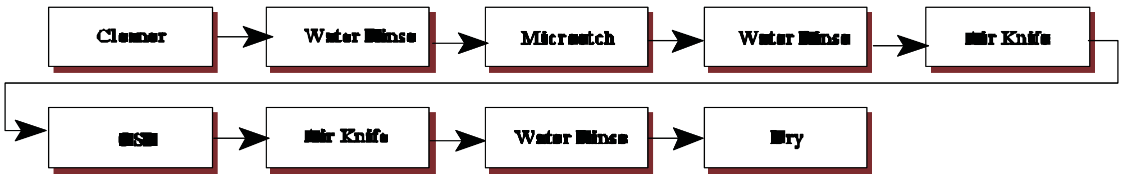
Table 7-22. Number of Nickel/Palladium/Gold Chemicals Subject to Applicable Federal Regulations

Regulation		No. of Chemicals	Regulation		No. of Chemicals
CWA	304b	5	EPCRA	313	10
	307a	5		302a	3
	311	12	SARA	110	6
	Priority Pollutant	5	TSCA	8d HSDR	1
CAA	111	5		MTL	4
	112b	5		8a PAIR	4
	112r	1	RCRA	U	--

Abbreviations and Definitions:
CWA 304b - Effluent Limitations Guidelines
CWA 307a - Toxic Pollutants
CWA 311 - Hazardous Substances
CAA 111 - Standards of Performance for New Stationary Sources of Air Pollutants-Equipment Leaks Chemical List
CAA 112b - Hazardous Air Pollutant
CAA 112r - Risk Management Program
EPCRA 313 - Toxic Chemical Release Inventory
EPCRA 302a - Extremely Hazardous Substances
SARA 110 - Superfund Site Priority Contaminant
TSCA 8d HSDR - Health & Safety Data Reporting Rules
TSCA MTL - Master Testing List
TSCA 8a PAIR - Preliminary Assessment Information Rule
RCRA U Waste - Characteristic hazardous waste

7.3.4 OSP Technology

Generic Process Steps and Typical Bath Sequence



Equipment Configurations Evaluated: Non-conveyorized and conveyorized.

Risk Screening and Comparison

Table 7-23 summarizes human and environmental hazards and risk concerns for chemicals in the OSP technology. The risk characterization identified occupational inhalation risk concerns for one chemical in the non-conveyorized OSP process and dermal risk concerns for three chemicals in the non-conveyorized OSP process and two chemicals in the conveyorized OSP process. No public health risk concerns were identified for the pathways evaluated.

Performance

The performance of the OSP technology was demonstrated at three test facilities, one of which operated conveyorized OSP equipment. Performance test results were not differentiated by the type of equipment configuration used. The Performance Demonstration determined that this technology has the capability of achieving comparable levels of performance to the HASL finish.

Production Costs and Resource Consumption

Computer simulation was used to model key operating parameters, including the time required to process a job consisting of 260,000 ssf and the amount of resources (water and energy) consumed. This information was analyzed with a hybrid cost model of traditional cost (i.e., capital costs, etc.) and activity-based costs to determine average manufacturing costs per ssf and water and energy consumption per ssf.

Both the non-conveyorized and conveyorized OSP technologies consume less water and energy and are more cost-effective than the baseline (non-conveyorized HASL process). Figure 7-4 lists the results of these analyses and illustrates the percent changes in costs and resource consumption from the baseline. Manufacturing costs, water consumption, and energy consumption for the non-conveyorized OSP process are less than the baseline by 69 percent, 38 percent, and 43 percent, respectively. The conveyorized OSP process is even more efficient than its non-conveyorized counterpart, reducing manufacturing costs from that of the baseline by 72 percent, and reducing water and energy consumption by 57 percent and 67 percent, respectively.

Table 7-23. Summary of Human Health and Environmental Risk Concerns for the OSP Technology

Chemical	Human Health Hazard and Occupational Risks [a]			Carcinogenicity Weight-of-Evidence Classification	Aquatic Risk Concerns
	Inhalation Risk Concerns [b]	Dermal Risk Concerns [c]	SAT Rank [d]		
Acetic acid	NE	No		None	No
Alkylaryl imidazole	NA	NE	LM	None	Yes
Aromatic imidizole product	NA	NE		None	NE
Arylphenol	NE	No	M	None	No
Copper ion	NA	Yes		Not classifiable (EPA Class D)	Not considered
Copper salt C	NA	Yes [e]		Not classifiable (EPA Class D)	Not considered
Copper sulfate pentahydrate	NA	Yes		Not classifiable (EPA Class D)	Not considered
Ethoxylated alkylphenol	NA	No [f]	LM	None	No
Ethylene glycol	Yes	No		None	No
Gum	NA	No [f]		None	No
Hydrochloric acid	No	NE		Not classifiable (IARC Group 3)	No
Hydrogen peroxide	No	No		Not classifiable (IARC Group 3)	No
Hydroxyaryl acid	NA	NE		None	No
Hydroxy aryl sulfonate	NA	No [f]	LM	None	No
Phosphoric acid	No	No		None	No
Sodium hydroxide	NA	NE		None	No
Sulfuric acid	NA	NE [g]		Human carcinogen (IARC Group 1)	No
Summary	No or NA: 14 NE: 2 Yes: 1	No: 8 NE: 6 Yes: 3		1 suspected or known	No: 12 Yes: 1 Not considered: 3

[a] Risk concerns are for surface finishing line operators (the most exposed individual).
[b] Inhalation risk concerns for non-conveyorized process only. Inhalation risk from fully enclosed, conveyorized process is assumed to be negligible.
[c] Dermal risk concerns apply to both conveyorized and non-conveyorized equipment unless otherwise noted.
[d] Structure-Activity Team rank for human health concerns:
LM: Low-Moderate concern; M: Moderate concern.
[e] Applied to non-conveyorized configuration only.
[f] Chemical has very low skin absorption (based on EPA's Structure-Activity Team evaluation); risk from dermal exposure not expected to be of concern.
[g] Although chronic toxicity values have not been established, repeated skin contact with low concentrations of sulfuric acid causes skin desiccation, ulceration of the hands, and chronic inflammation around the nails.
NA: Not Applicable. Inhalation exposure level was not calculated because the chemical is not volatile (vapor pressure below 1 x 10^{-3} torr) and is not used in any air-sparged bath.
NE: Not Evaluated; due to lack of toxicity measure.

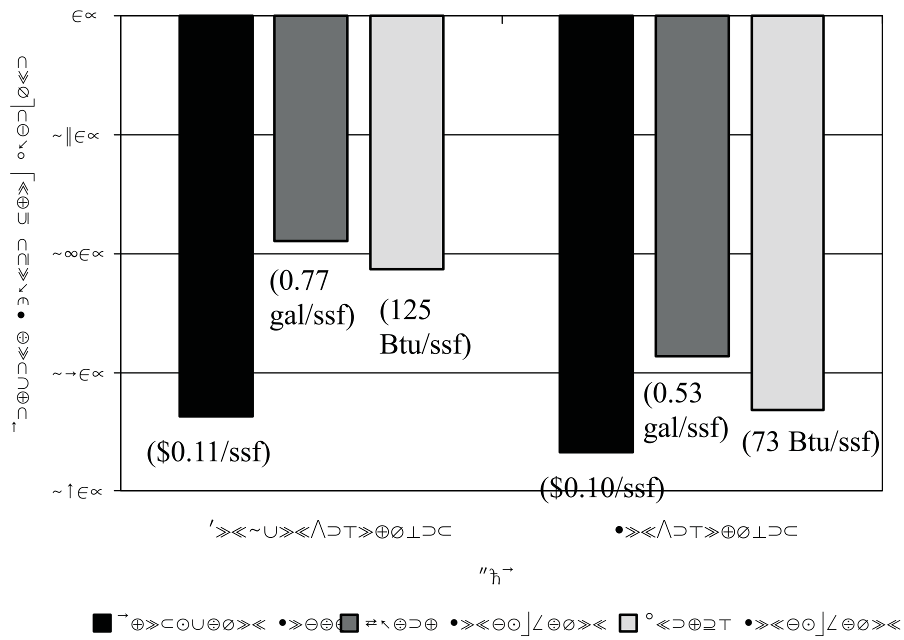


Figure 7-4. Production Costs and Resource Consumption of OSP Technology (Percent Change from Baseline with Actual Values in Parentheses)

Regulatory Concerns

Chemicals contained in the OSP technology are regulated by the CWA, CAA, EPCRA, SARA, and TSCA. None of the OSP process chemicals were regulated under RCRA. A summary of the number of OSP chemicals subject to applicable federal regulations is presented in Table 7-24.

Social Benefits and Costs

A qualitative assessment of the private and external benefits and costs of the this technology suggests a mixture of benefits and costs to society if PWB manufacturers switched to the OSP technology from the baseline. For the aspects included in the evaluation, changing from baseline to OSP may result in:

- benefits from decreased manufacturing cost and ecological risk (based on fewer chemicals of concern), decreased water and energy use;
- mixed results for worker risk (based on fewer carcinogens or suspected carcinogens used in the process, but more chemicals of concern for non-cancer worker risk); and
- no discernible cost or benefit for risk to the public.

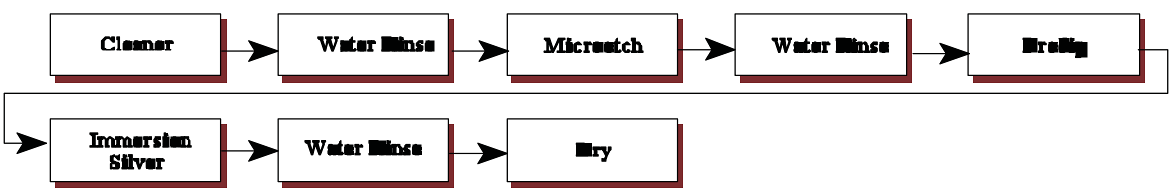
Table 7-24. Number of OSP Chemicals Subject to Applicable Federal Regulations

Regulation		No. of Chemicals	Regulation		No. of Chemicals
CWA	304b	2	EPCRA	313	5
	307a	2		302a	2
	311	5	SARA	110	2
	Priority Pollutant	2	TSCA	8d HSDR	1
CAA	111	3		MTL	2
	112b	2		8a PAIR	1
	112r	1	RCRA	U	--

Abbreviations and Definitions:
CWA 304b - Effluent Limitations Guidelines
CWA 307a - Toxic Pollutants
CWA 311 - Hazardous Substances
CAA 111 - Standards of Performance for New Stationary Sources of Air Pollutants-Equipment Leaks Chemical List
CAA 112b - Hazardous Air Pollutant
CAA 112r - Risk Management Program
EPCRA 313 - Toxic Chemical Release Inventory
EPCRA 302a - Extremely Hazardous Substances
SARA 110 - Superfund Site Priority Contaminant
TSCA 8d HSDR - Health & Safety Data Reporting Rules
TSCA MTL - Master Testing List
TSCA 8a PAIR - Preliminary Assessment Information Rule
RCRA U Waste - Characteristic hazardous waste

7.3.5 Immersion Silver Technology

Generic Process Steps and Typical Bath Sequence



Equipment Configurations Evaluated: Conveyorized.

Risk Screening and Comparison

Table 7-25 summarizes human and environmental hazards and risk concerns for chemicals in the immersion silver technology. The risk characterization did not identify any occupational or dermal risk concerns for chemicals in the conveyorized immersion silver process. No public health risk concerns were identified for the pathways evaluated.

Table 7-25. Summary of Human Health and Environmental Risk Concerns for the Immersion Silver Technology

Chemical	Human Health Hazard and Occupational Risks [a]			Carcinogenicity Weight-of-Evidence Classification	Aquatic Risk Concerns
	Inhalation Risk Concerns [b]	Dermal Risk Concerns [c]	SAT Rank [d]		
1,4-Butenediol	NA	NE	LM	None	No
Alkylamino acid A	NA	No [e]	LM	None	No
Fatty amine	NA	No [e]	M	None	No
Hydrogen peroxide	NA	No		Not classifiable (IARC Group 3)	Yes
Nitrogen acid	NA	NE		None	No
Phosphoric acid	NA	No		None	No
Silver nitrate	NA	No		Not classifiable (EPA Class D)	Not considered
Sodium hydroxide	NA	NE		None	No
Sulfuric acid	NA	NE [f]		Human carcinogen (IARC Group 1)	No
Summary	NA: 9	No: 5 NE: 4		1 suspected or known	No: 7 Yes: 1 Not considered: 1

[a] Risk evaluated for conveyorized process only. Inhalation risk from fully enclosed, conveyorized process is assumed to be low. Risk concerns are for line operator (the most exposed individual).
[b] Inhalation risk concerns for non-conveyorized process only. Inhalation risk from fully enclosed, conveyorized process is assumed to be negligible.
[c] Dermal risk concerns apply to both conveyorized and non-conveyorized equipment.
[d] Structure-Activity Team rank for human health concerns:
LM: Low-Moderate concern; M: Moderate concern.
[e] Chemical has very low skin absorption (based on EPA's Structure-Activity Team evaluation); risk from dermal exposure is not expected to be of concern.
[f] Although chronic toxicity values have not been established, repeated skin contact with low concentrations of sulfuric acid causes skin desiccation, ulceration of the hands, and chronic inflammation around the nails.
NE: Not Evaluated; due to lack of toxicity measure.
NA: Not Applicable. Inhalation exposure level was assumed to be negligible for conveyorized lines.

Performance

The performance of the immersion silver technology was demonstrated at two test facilities. The Performance Demonstration determined that this technology has the capability of achieving comparable levels of performance to the HASL finish. In addition, the immersion silver process is both gold and aluminum wire-bondable, though testing of wire-bondability was not included in the performance testing protocol.

Production Costs and Resource Consumption

Computer simulation was used to model key operating parameters, including the time required to process a job consisting of 260,000 ssf and the amount of resources (water and energy) consumed. This information was analyzed with a hybrid cost model of traditional cost (i.e., capital costs, etc.) and activity-based costs to determine average manufacturing costs per ssf and water and energy consumption per ssf.

Analysis results showed that the conveyorized immersion silver process consumed less water and was more cost-effective than the baseline non-conveyorized HASL process, while consuming more energy. Average production costs for immersion silver were \$0.28/ssf, while water and energy consumption rates were determined to be 0.53 gal/ssf and 287 Btu/ssf, respectively. Figure 7-5 lists the results of these analyses and illustrates the percent changes in costs and resource consumption from the baseline. Manufacturing costs and water consumption are less than the baseline by 22 percent and 57 percent, respectively, while energy consumption increased by 32 percent.

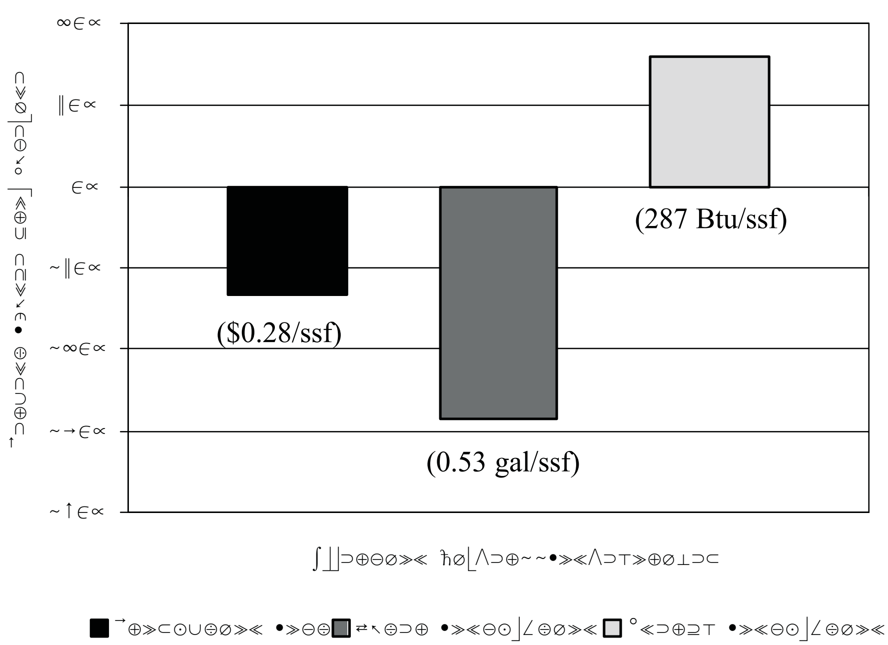


Figure 7-5. Production Costs and Resource Consumption of Immersion Silver Technology (Percent Change from Baseline with Actual Values in Parentheses)

Regulatory Concerns

Chemicals contained in the immersion silver technology are regulated by the CWA, CAA, EPCRA, SARA, and TSCA. None of the immersion silver process chemicals were regulated under RCRA. A summary of the number of immersion silver chemicals subject to applicable federal regulations is presented in Table 7-26.

Table 7-26. Number of Immersion Silver Chemicals Subject to Applicable Federal Regulations

Regulation		No. of Chemicals	Regulation		No. of Chemicals
CWA	304b	1	EPCRA	313	3
	307a	1		302a	3
	311	5	SARA	110	1
	Priority Pollutant	1	TSCA	8d HSDR	--
CAA	111	1		MTL	1
	112b	1		8a PAIR	1
	112r	--	RCRA	U	--

Abbreviations and Definitions:
CWA 304b - Effluent Limitations Guidelines
CWA 307a - Toxic Pollutants
CWA 311 - Hazardous Substances
CAA 111 - Standards of Performance for New Stationary Sources of Air Pollutants-Equipment Leaks Chemical List
CAA 112b - Hazardous Air Pollutant
CAA 112r - Risk Management Program
EPCRA 313 - Toxic Chemical Release Inventory
EPCRA 302a - Extremely Hazardous Substances
SARA 110 - Superfund Site Priority Contaminant
TSCA 8d HSDR - Health & Safety Data Reporting Rules
TSCA MTL - Master Testing List
TSCA 8a PAIR - Preliminary Assessment Information Rule
RCRA U Waste - Characteristic hazardous waste

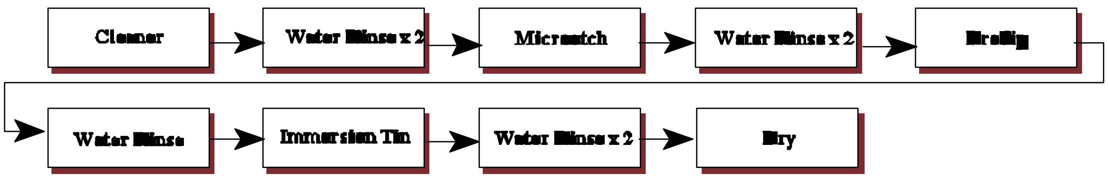
Social Benefits and Costs

A qualitative assessment of the private and external benefits and costs of the this technology suggests a mixture of benefits and costs to society if PWB manufacturers switched to the immersion silver technology from the baseline. For the aspects included in the evaluation, changing from baseline to immersion silver may result in:

- benefits from decreased manufacturing cost, worker and ecological risk (based on fewer chemicals of concern), and decreased water use;
- costs from increased energy use; and
- no discernible cost or benefit for risk to the public.

7.3.6 Immersion Tin Technology

Generic Process Steps and Typical Bath Sequence



Equipment Configurations Evaluated: Non-conveyorized and conveyorized.

Risk Screening and Comparison

Table 7-27 summarizes human and environmental hazards and risk concerns for chemicals in the immersion tin technology. The risk characterization identified occupational dermal risk concerns for one chemical for either equipment configuration. No occupational inhalation concerns or public health risk concerns were identified for the pathways evaluated.

Table 7-27. Summary of Human Health and Environmental Risk Concerns for the Immersion Tin Technology

Chemical	Human Health Hazard and Occupational Risks [a]			Carcinogenicity Weight-of-Evidence Classification	Aquatic Risk Concerns
	Inhalation Risk Concerns [b]	Dermal Risk Concerns [c]	SAT Rank [d]		
Aliphatic acid D	No	No		None	No
Alkylalkyne diol	NA	No [e]	L	None	No
Alkylimine dialkanol	NA	No [e]	M	None	No
Alkylamino acid B	NA	No		None	No
Alkylaryl sulfonate	NE	No [e]	L	None	No
Alkylphenol ethoxylate	NA	No [e]	LM	None	No
Bismuth compound	NA	No [f]	M	None	No
Citric acid	NA	No [e]	L	None	No
Cyclic amide	No	No		None	No
Ethoxylated alkylphenol	NA	No [e]	LM	None	No
Ethylene glycol monobutyl ether	No	No		None	No
Fluoboric acid	NA	NE		None	No
Hydrochloric acid	No	NE		Not classifiable (IARC Group 3)	No
Hydroxy carboxylic acid	No	No		None	No
Methane sulfonic acid	NA	NE		None	No
Phosphoric acid	No	No		None	No
Potassium peroxymonosulfate	NA	No [e]	M	None	NC: Yes C: No

Chemical	Human Health Hazard and Occupational Risks [a]			Carcinogenicity Weight-of-Evidence Classification	Aquatic Risk Concerns
	Inhalation Risk Concerns [b]	Dermal Risk Concerns [c]	SAT Rank [d]		
Quantenary alkyl ammonium chlorides	NA	No [e]	M	None	No
Silver salt	NA	No		Not classifiable [g]	Not considered
Sodium benzene sulfonate	NA	No [e]	M	None	No
Sodium phosphorus salt	NA	NE		None	No
Stannous methane sulfonic acid	NA	No		Not classifiable (EPA Class D)	Not considered
Sulfuric acid	NA	No		Human carcinogen (IARC Group 1)	No
Thiourea	NA	NE		Possibly carcinogenic (IARC Group 2B)	No
Tin chloride	NA	No		Not classifiable (EPA Class D; IARC Group 3)	Not considered
Unspecified tartrate	NA	No		None	No
Urea	NA	No		None	No
Vinyl polymer	NA	No		Not classifiable [g]	No
Urea compound C	NE	Yes		None	No
Summary	No or NA: 27 NE: 2 Yes: 0	No: 23 NE: 5 Yes: 1		2 suspected or known	No: 25 Yes: 1 Not considered: 3

[a] Risk concerns are for surface finishing line operators (the most exposed individual).
[b] Inhalation risk concerns for non-conveyorized process only. Inhalation risk from a fully enclosed, conveyorized process is assumed to be negligible.
[c] Dermal risk concerns apply to both conveyorized and non-conveyorized equipment.
[d] Structure-Activity Team rank for human health concerns:
L: Low concern; LM: Low-Moderate concern; M: Moderate concern.
[e] Chemical has very low skin absorption (based on EPA's Structure-Activity Team evaluation); risk from dermal exposure is not expected to be of concern.
[f] No absorption expected through skin, however, in water this compound will cause irritation of all moist tissues (SAT report).
[g] Specific EPA and/or IARC groups not reported in order to protect proprietary chemical identities.
NE: Not Evaluated; due to lack of toxicity measure.
NA: Not Applicable. Inhalation exposure level was not calculated because the chemical is not volatile (vapor pressure below 1 x 10^{-3} torr) and is not used in any air-sparged bath.

Performance

The performance of the immersion tin technology was demonstrated at four test facilities, two of which operated conveyorized immersion tin equipment. Performance test results were not differentiated by the type of equipment configuration used. The Performance Demonstration determined that this technology has the capability of achieving comparable levels of performance to the HASL finish.

Production Costs and Resource Consumption

Computer simulation was used to model key operating parameters, including the time required to process a job consisting of 260,000 ssf and the amount of resources (water and energy) consumed. This information was analyzed with a hybrid cost model of traditional cost (i.e., capital costs, etc.) and activity-based costs to determine average manufacturing costs per ssf and water and energy consumption per ssf.

Both the non-conveyorized and conveyorized methods of immersion tin were more economical than the baseline process, with the non-conveyorized process proving less expensive ($0.18/ssf vs. $0.25/ssf) overall. Only the conveyorized immersion tin process showed a reduction in water consumption, while both equipment configurations consumed more energy than the baseline. Figure 7-6 lists the results of these analyses and illustrates the percent changes in costs and resource consumption for either equipment configuration from the baseline. Non-conveyorized immersion tin manufacturing costs are less than the baseline by 50 percent, while the water and energy consumption rates increased by 46 percent and 33 percent, respectively. Manufacturing costs and the water consumption for the conveyorized immersion tin process are less than the baseline by 31 percent and 29 percent respectively, while energy consumption increased 139 percent.

Regulatory Concerns

Chemicals contained in the immersion tin technology are regulated by the CWA, CAA, EPCRA, SARA, and TSCA. In addition, two of the chemicals in the immersion tin process chemicals is regulated under RCRA. A summary of the number of immersion tin chemicals subject to applicable federal regulations is presented in Table 7-28.

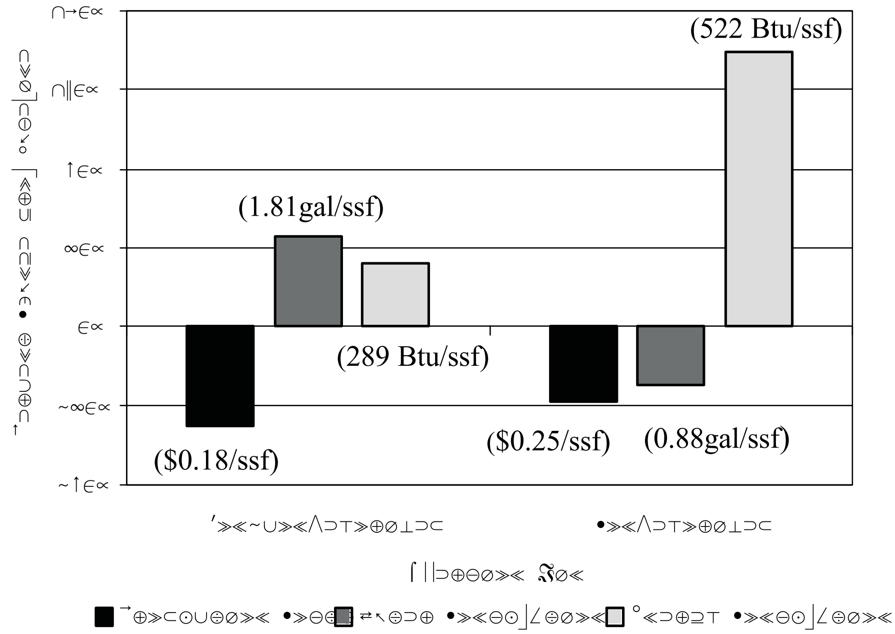


Figure 7-6. Production Costs and Resource Consumption of Immersion Tin Technology
(Percent Change from Baseline with Actual Values in Parentheses)

Table 7-28. Number of Immersion Tin Chemicals Subject to Applicable Federal Regulations

Regulation		No. of Chemicals	Regulation		No. of Chemicals
CWA	304b	1	EPCRA	313	7
	307a	1		302a	2
	311	6	SARA	110	1
	Priority Pollutant	1	TSCA	8d HSDR	2
CAA	111	3		MTL	4
	112b	2		8a PAIR	3
	112r	1	RCRA	U	2

Abbreviations and Definitions:
CWA 304b - Effluent Limitations Guidelines
CWA 307a - Toxic Pollutants
CWA 311 - Hazardous Substances
CAA 111 - Standards of Performance for New Stationary Sources of Air Pollutants-Equipment Leaks Chemical List
CAA 112b - Hazardous Air Pollutant
CAA 112r - Risk Management Program
EPCRA 313 - Toxic Chemical Release Inventory
EPCRA 302a - Extremely Hazardous Substances
SARA 110 - Superfund Site Priority Contaminant
TSCA 8d HSDR - Health & Safety Data Reporting Rules
TSCA MTL - Master Testing List
TSCA 8a PAIR - Preliminary Assessment Information Rule
RCRA U Waste - Characteristic hazardous waste

Social Benefits and Costs

A qualitative assessment of the private and external benefits and costs of the this technology suggests a mixture of benefits and costs to society if PWB manufacturers switched to the immersion tin technology from the baseline. For the aspects included in the evaluation, changing from baseline to non-conveyorized immersion tin may result in:

- benefits from decreased manufacturing cost, worker and ecological risk (based on fewer chemicals of concern);
- costs from increased water and energy use; and
- no discernible cost or benefit for risk to the public.

Changing from baseline to conveyorized immersion tin may result in:

- benefits from decreased manufacturing cost, worker and ecological risk (based on fewer chemicals of concern) and decreased water use;
- costs from increased energy use; and
- no discernible cost or benefit for risk to the public.

REFERENCES

Mishan, E.J. 1976. Cost-Benefit Analysis. Praeger Publishers: New York.